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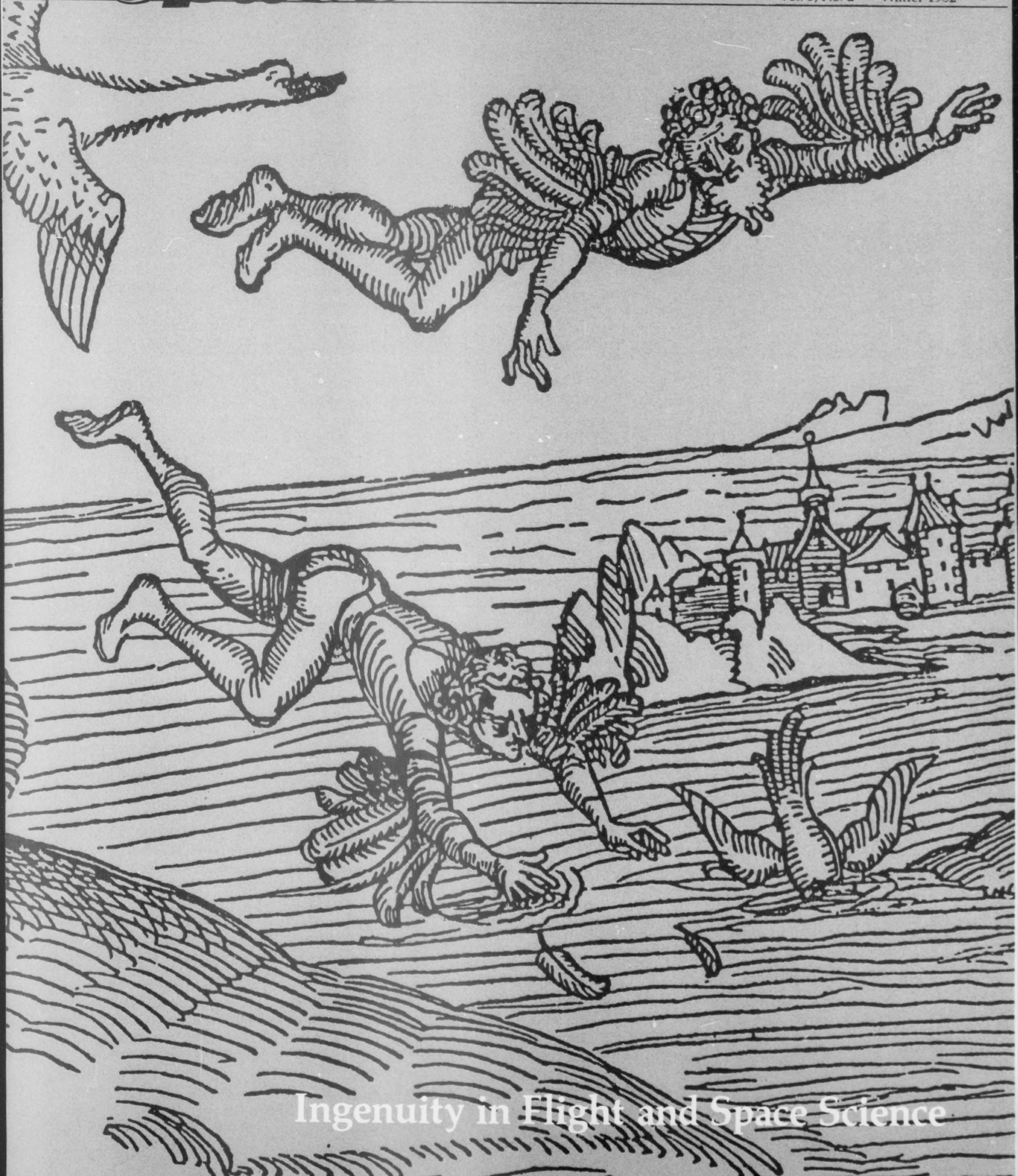

Ingenuity in Flight and Space Science

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For brevity, the National Air and Space Museum is often referred to in these pages as NASM. The National Aeronautics and Space Administration is NASA.

Briefing

Ingenuity—Help Needed

Noel W. Hinners
Director, NASM

This issue of *Air & Space* deals with ingenuity, citing several individuals who possessed that quality and applied it to the solution of a problem. Ingenuity has long been associated with Americans, as attested to by the timeworn yet apt phrase, "Good old Yankee ingenuity." Indeed, the blossoming of ingenuity, in response to a host of real problems over about the past 100 years, had made the United States the leader of the technological revolution. Judging from the increasing percentage of foreign-held U.S. patents and the negative balance of payments, one may conclude that lately the United States has lost much of that lead. Having recognized our competitive lapse, we are now searching for ways to regain it. Much is heard about tax incentives to industry, labor participation in production decisions, less government regulation, and increased long-term research and development. All to the good, I believe, but are they the total answer? Most emphatically, NO! Two other significant factors that must be addressed are the increasing scientific and technological illiteracy of our population and the diminished role of the individual in our society.

The illiteracy problem is especially troublesome because of current fiscal problems. The country requires, through its elected representatives, the consent of its citizenry in setting government budget priorities and policies affecting scientific and technological research and development. In this crucial period of budget slash and burn, high priority must be given to reestablishing our base of research and development, which is built upon real people, not statistical nonentities. So, as part of the solution to the problem, we need both a scientifically and technologically literate voting citizenry and a stimulated student body, starting in the grade schools. Neither of these needs is well served by disproportionate budget cuts in science-education programs of such organizations as the National Science Foundation.

A contributing factor to decreased U.S. competitiveness is the diminished role of the individual. Certain aspects of our democracy have, to some degree, encouraged an unhealthy submergence of the recognition of individual differences in talent and productivity. Likewise, the team approach to science and engineering has the built-in potential to stifle ingenuity and create the vacuousness of "group think."

Quality education of all our youth is an obvious first step towards rectifying these deficiencies, enabling us to tap what is probably widespread but latent ingenuity. Inventors of the past demonstrated personal traits such as single-minded determination in overcoming challenges and a willingness to take risks. Oftentimes, the whole invention process is encouraged by relative financial independence, be it from parental largess (e.g., Charles Darwin), stable business (the Wright brothers), or industrial backing (MacCready's Solar Albatross). In addition to the obvious advantage of financial backing for procuring materials or technical help, the most precious commodity money buys is time—to think, to tinker, to follow blind leads, to try again.

Time and money are as much the mother of invention as is necessity. However, you as educators can help. You are the ones who often get first crack at nurturing and encouraging individuals, challenging them to think and to value mental activity, and giving them the self-confidence that leads to the determination and risk-taking that are essential to innovation.

The Wright Brothers

Tom D. Crouch
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Wilbur (1867-1912) left, and Orville Wright (1871-1948).

George Bernard Shaw once remarked that the public perception of any great invention or discovery passes through three chronological phases. At first we refuse to believe that the marvel has been accomplished. Next we decide that it was not, after all, so great an achievement as we had at first supposed. Finally we seem compelled to prove that someone else did it first.

The story of the invention of the airplane offers a perfect illustration of the truth of Shaw's tongue-in-cheek observation. Wilbur and Orville Wright altered the course of human history on the morning of Dec. 17, 1903, yet when the first reports of the flights were received, they were quickly discounted. The Wrights continued to experiment for two more years while most of the world believed that the airplane was still only a distant pipe dream. When the Wright Flyer was unveiled to the public in 1908, mar , Europeans, while accepting the fact that the Wrights had been the first to fly, argued that the brothers' contribution to flight technology had not been that important. Finally, over the past 40 years, one candidate after another has been advanced for the honor of having flown an airplane before Wilbur and Orville Wright did.

There is not now, nor has there ever been, any serious evidence to suggest that anyone other than the Wright brothers invented the airplane. Moreover, the Wrights invented the airplane in a much truer sense than S.F.B. Morse invented the telegraph, Robert Fulton the steamboat, or Thomas Edison the light bulb and motion picture. By virtue of their brilliant technical insight and sheer engineering genius, the Wrights overcame problems that had long blocked the route to a successful airplane. They cut straight to the heart of matters, which their predecessors had either skirted or attacked from a totally incorrect point of view. They undertook crucial quantitative analyses in essential areas where other experimenters had assumed the accuracy of existing data. In essence, they functioned more successfully as engineers than did men with the best formal training and many years experience.

In a sense, the story of the Wright brothers and the airplane seems almost too good to be true. How, in less than four active years of experimentation, were these two small-town businessmen able to achieve a goal that had eluded the best minds of the ages? The answer is found in a complex chain of events that began in the summer of 1896.

The Wright brothers, aged 29 and 25 that year, were the sons of a bishop in the United Brethren Church. For several years of his life, Wilbur, the elder, remained unemployed, a semi-invalid because of an ice-hockey accident. Orville, who left high school before graduation, had tried his hand at many tasks but had achieved little financial success.

Their second joint venture (the first was printing), the Wright Cycle Company, provided a reasonable income and an outlet for their mechanical interests but left the brothers with a great deal of free time, particularly during the winter.

The year 1896 was a crucial one for them. Magazines and newspapers had been carrying reports of men taking to the skies. In Germany, Otto Lilienthal was concluding his sixth successful season of trials with a series of manned hang gliders. By the time of his death in a glider accident in August 1896, he had convinced the most obstinate doubters that human beings could fly on wings of their own construction. Octave Chanute, a world-famous civil engineer, was emulating Lilienthal that summer at an aerial-experiment station on the Lake Michigan sand dunes near Miller, Ind.

Their interest whetted by published reports, the Wrights spent the next three years slowly absorbing the flying-machine and bird-flight literature available at home and in the library. A letter to the Smithsonian Institution produced suggestions for further reading. Correspondence with Chanute cemented a friendship with this man who was to become their chief confidant.

Though the aeronautical literature of the period was a confusing mix of speculation and theory, one of the early marks of the Wright genius was their ability to winnow a few useful ideas from this contradictory morass. It was clear to them, for example, that the flight tests of manned gliders, as advocated by Lilienthal, offered a more rational path to success with a powered machine than did the use of scale models. Moreover, they believed that the practical success of Lilienthal guaranteed the accuracy of the air-pressure tables that he had developed for use in planning the wing-surface area of a flying machine. Chanute had suggested the most efficient aircraft structure in his classic biplane glider of 1896.

More important than these bits of information, however, was the fact that their review of previous work in aeronautics enabled the Wrights to identify the most troublesome problem that had blocked the route to success for others—control.

The Wrights recognized the almost universal search for a system of automatic stability as a blind alley that had led and was leading virtually all other aeronautical experimenters astray. The brothers were resolved that their pilot would be in absolute command of the motion and attitude of his machine at all times.

It had long been recognized that the presence of a horizontal elevator would enable an aircraft to climb or dive, while a vertical rudder could be used to keep the nose of the craft pointed in the desired direction. The longitudinal, or roll, axis was another matter, however. Most of the inventors who had tackled the problems of flight prior to the Wrights saw such control as necessary only to correct for the rise or fall of wing tips struck by gusts. They assumed that the aircraft could be turned to the right or left by the action of the rudder alone.

As experienced bicycle riders, the Wrights realized that bicycles and airplanes are not naturally stable platforms. Rather, the operator must maintain equilibrium or fall. Such a craft cannot negotiate a sharp turn simply by angling a front wheel or a rudder. In order to maintain balance, it is necessary to lean into the turn. In the case of the airplane this requires a dip of the wing tip in the desired direction. Thus the Wrights sought a method of dipping or raising either wing at will, whereas other experimenters searched for a device to counter such an action. This realization of the necessity for active longitudinal control set the two Daytonians apart from other flying-machine innovators.

Wing warping was the Wrights' answer. If a helical twist could be imparted to the wings the shift in pressure would force one wing tip down and the other up. They first applied the technique in a small kite built during the summer of 1899, then planned the construction of a man-carrying device embodying the same principle.

As they prepared to enter the active phase of their work, the Wrights were only four years from ultimate success. Lilienthal, Langley, Chanute, and others had struggled unsuccessfully for decades to develop a powered flying machine. The Wrights would accomplish the task in seven years, only four of which were devoted to active trials.

The wing-warping system allowed the Wrights to operate gliders with much larger wingspans than those of other designers. The performance of these craft astounded Chanute and everyone else who visited the camp near Kitty Hawk. Yet the Wrights were so dissatisfied at the close of the 1901 season that they seriously considered abandoning aviation. They had failed to achieve the results predicted by their calculations. Ultimately unwilling to walk away from the puzzle, they undertook a series of wind-tunnel tests in order to check the validity of the Lilienthal air-pressure tables on which they had based their preliminary performance computations.

This episode is the clearest example of the intuitive engineering genius that the Wrights brought to bear on the problems of flight. While the renowned Langley clung to cut-and-try empiricism, the self-educated Wrights broke entirely new ground with their homemade wind tunnel. Their 1902 glider, which embodied the corrected wind-tunnel data, performed spectacularly and enabled the Wrights to modify their control system. They realized that they stood very close to final success and turned their attention to the propulsion system. Unable to locate a suitable lightweight engine at a reasonable price, they designed a four-cylinder power plant. Constructed by Charles Taylor, a mechanic in the bike shop, the engine was in many respects quite primitive, producing roughly 16 hp when first started, but dropping to about 12 hp after a minute or so of operation.

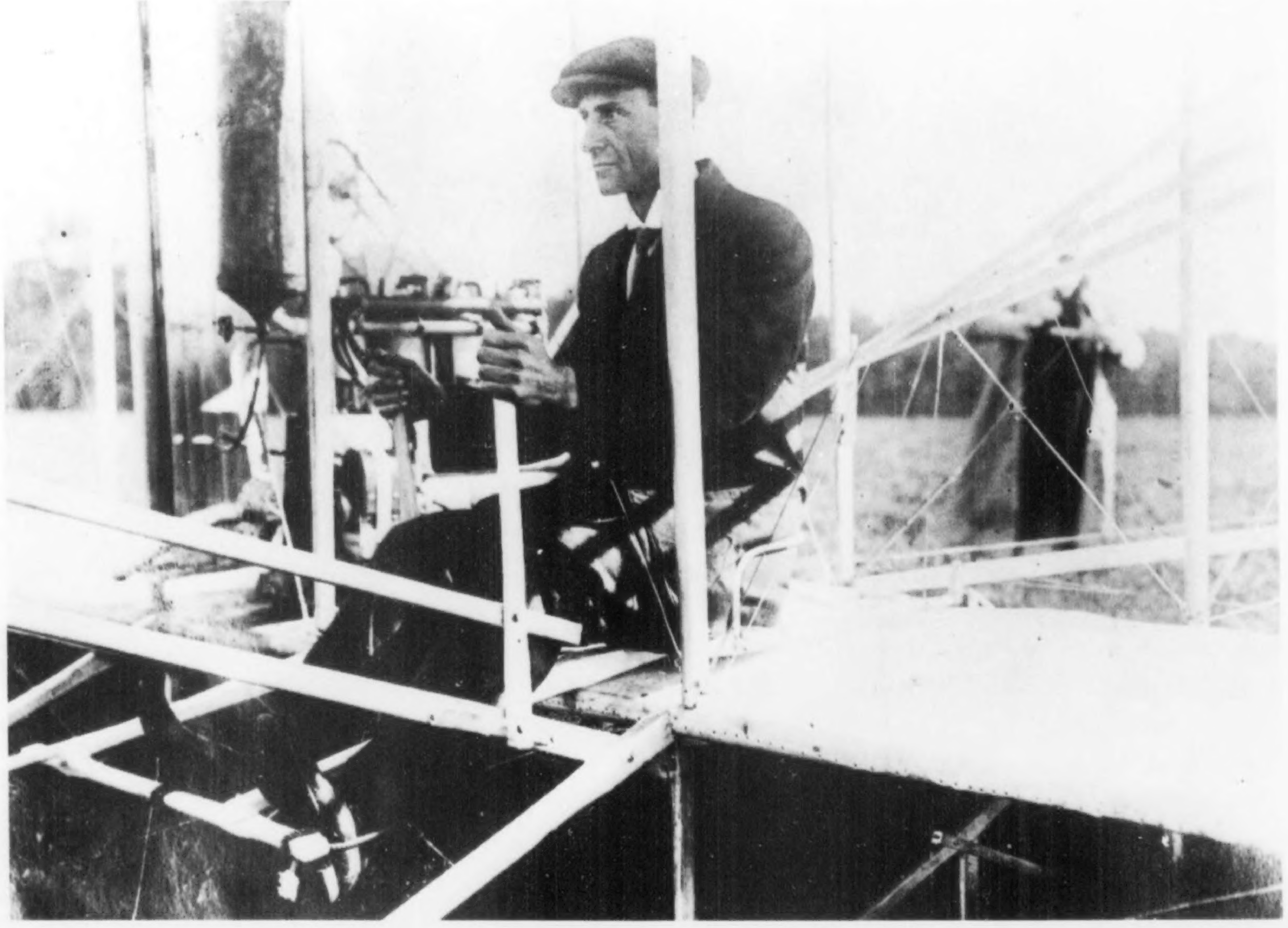
In the matter of propellers, the Daytonians were far in advance of their fellows. The brothers were the first to understand that an aircraft propeller is not an "air screw" in a literal sense. Rather, it is a rotary wing, the lift of which draws the airplane forward.

With their new engine and propellers on hand and work on the structure of the large aircraft nearing completion, the Wrights began planning for their fourth season at Kitty Hawk. This year, 1903, they would add a new shed to their camp to supplement the original building constructed in 1901. For the first time, they would be flying two machines, the 1902 glider having been refurbished for practice flying while the powered machine was being put together.

The brothers arrived at their Kitty Hawk camp at 1:00 P.M. on Sept. 25, 1903. They had chosen this site after correspondence with Chanute, U.S. Weather Bureau officials, and local residents. Attracted by reports of steady winds, which would keep their gliders aloft, hills from which to launch the gliders and isolation that would permit them privacy, the brothers developed an affection for the self-reliant "Kitty Hawkers" (as they called them).

The Wright camp was situated just north of the Kill Devil Hills, a range of sand hummocks that derived its name, according to one account, "because sailors say it is enough to kill the devil to navigate this part of the [Albermarle]

A determined Wilbur in a 1908 model "A" Wright Flyer.



sound." The Wrights' only immediate neighbors were the Kill Devil Hill Life Saving Station crew, located roughly a mile from their camp. The closest population center, the small village of Kitty Hawk, lay some four miles to the north. Kitty Hawk boasted its own lifesaving station, a U.S. weather bureau, a post office serviced by a small mail boat from Manteo, and scattered houses.

But living conditions on the Outer Banks shocked the brothers. Sand sifted through the smallest cracks. Mosquitoes, as Orville reported in 1901, "chewed us clear through our underwear and socks. Lumps began swelling up all over my body. . . . Misery! Misery!

On arrival in 1903, the brothers discovered that a storm had lifted their original hangar from its foundations. Having just repaired it and completed a second shed, they were promptly assaulted by a ferocious gale. By November, cold weather had set in. In a letter to his father and sister, Wilbur commented that "In addition to . . . 1, 2, 3 and 4 blanket nights, we now have 5 blanket nights, & 5 blankets & 2 quilts. Next come 5 blankets, 2 quilts & fire; then 5, 2, fire & hot water jug. . . . Next comes the addition of sleeping without undressing, then shoes & hats, and finally overcoats."

Orville working on the 1911 Kitty Hawk glider.

A makeshift stove constructed from a carbide can provided heat but filled the building with smoke so thick that when the brothers sat down to eat, the soot on the ceiling began dropping onto their plates. They added legs, chimney, and dampers to the stove, which eased the situation.

In spite of the difficulties, the Wrights forged ahead with trials of the 1902 glider and worked to complete the powered machine. By early November, as Manly and Langley were waiting for a break in the weather over the Potomac, the brothers were encountering problems with a rough-running power plant and damaged tubular propeller shafts that eventually forced Orville's quick return to Dayton to supervise work on a new set of solid spring-steel shafts.

Finally on December 14, preparations seemed complete. The toss of a coin determined that Wilbur would have the honor of the first full trial of the powered machine. The craft lifted off on this occasion, but nosed up too sharply and fell to earth, causing slight damage. Three days later, with repairs complete, they were ready for a second trial.

The morning of December 17 dawned cold. The puddles of standing water had frozen overnight, and a 43 kmph (27 mph) wind was blowing from the north. Hoping that the wind might abate, the brothers enjoyed a leisurely breakfast and remained indoors until 10:00 A.M. when they decided to make the trial.

They hung out a signal to summon the volunteer ground crew from the Kill Devil Station. The Wrights then maneuvered four 5 m- (15 ft.-) sections of two-by-fours, the tops of which had been sheathed in metal, to a level area some 24 m (80 ft.) west of their buildings. The aircraft, which would ride along this takeoff rail on a truck constructed of two modified bicycle hubs, was then taken out of the hangar and prepared for flight.

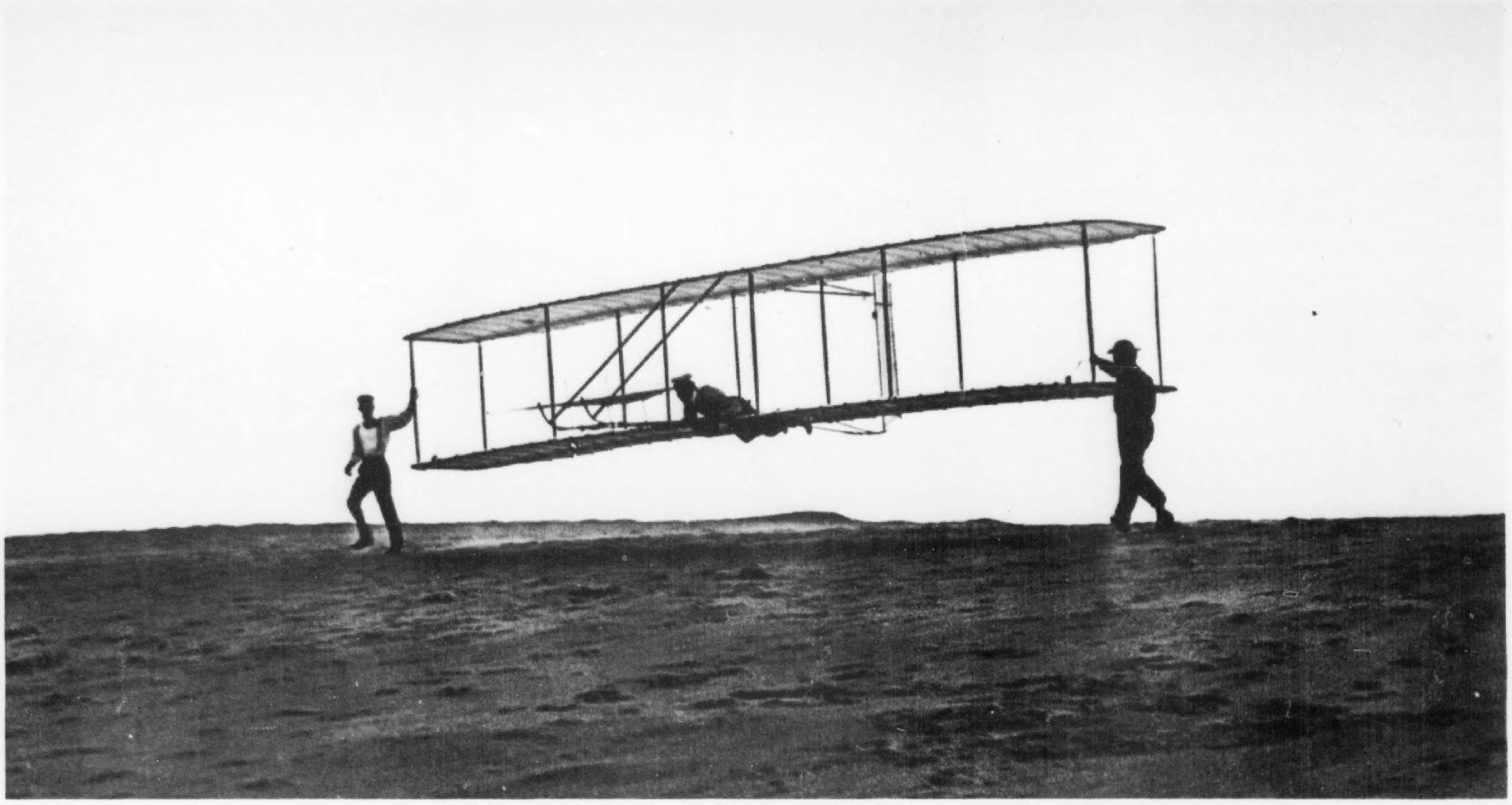
Work in the biting cold was difficult, requiring frequent retreats to the comfort of the carbide-can stove, but by the time John Daniels, W.S. Dough, and A.D. Etheridge arrived from the Kill Devil Station, preparations were nearing completion. Two visitors, W.C. Brinkley from Manteo and young Johnny Moore from Nags Head, accompanied the lifesavers. Robert Wescott, who had remained on duty at Kill Devil, watched the proceedings through a spyglass, while 6.4 km (4 mi.) away Capt. S.J. Payne, chief of the Kitty Hawk Station, trained his telescope on the men clustered around the plane.

At about 10:30 A.M. a few drops of gasoline were pumped into each cylinder. The coil box for starting was attached. The engine was allowed to run for several minutes while Wilbur and Orville discussed the situation. One of the witnesses years later recalled that "we couldn't help notice how they held onto each other's hand, sort o'like they hated to let go; like two folks parting who weren't sure they'd ever see each other again."

Finally, the two shook hands and Orville climbed into place beside the engine, prone on the lower wing with his feet braced against a board tacked to the trailing edge. His hips lay in a cradle free to move from side to side. To bank to the right, or to raise the left wing tip, he would shift the cradle to the right. This action would impart the correct warp to the wings and turn the rudder to the proper angle. With his left hand Orville grasped the elevator lever that would, he hoped, control the rise or fall of his machine.

His right hand operated a second lever that had only three positions. In the "off" position, it was pointed slightly to the right over the leading edge. When pushed straight forward, it opened the cock connecting the 2l (1/2 gal.) gasoline tank to the engine and permitted starting. When Orville was prepared to begin the flight he would pull the lever to the left, slipping a line that bound the aircraft and the truck to the rail and permitting them to move forward. At the same time, a stopwatch, the anemometer that served as an airspeed indicator, and the engine-revolution counter were set in motion. The lever was not a throttle, for the engine had only two speeds, on and off. Upon landing, however, the pilot would shove the control to the right to shut off the gas and kill the engine.

With Orville in place, Wilbur walked to the cluster of witnesses. Daniels was dispatched to man the camera pointed at the end of the rail.



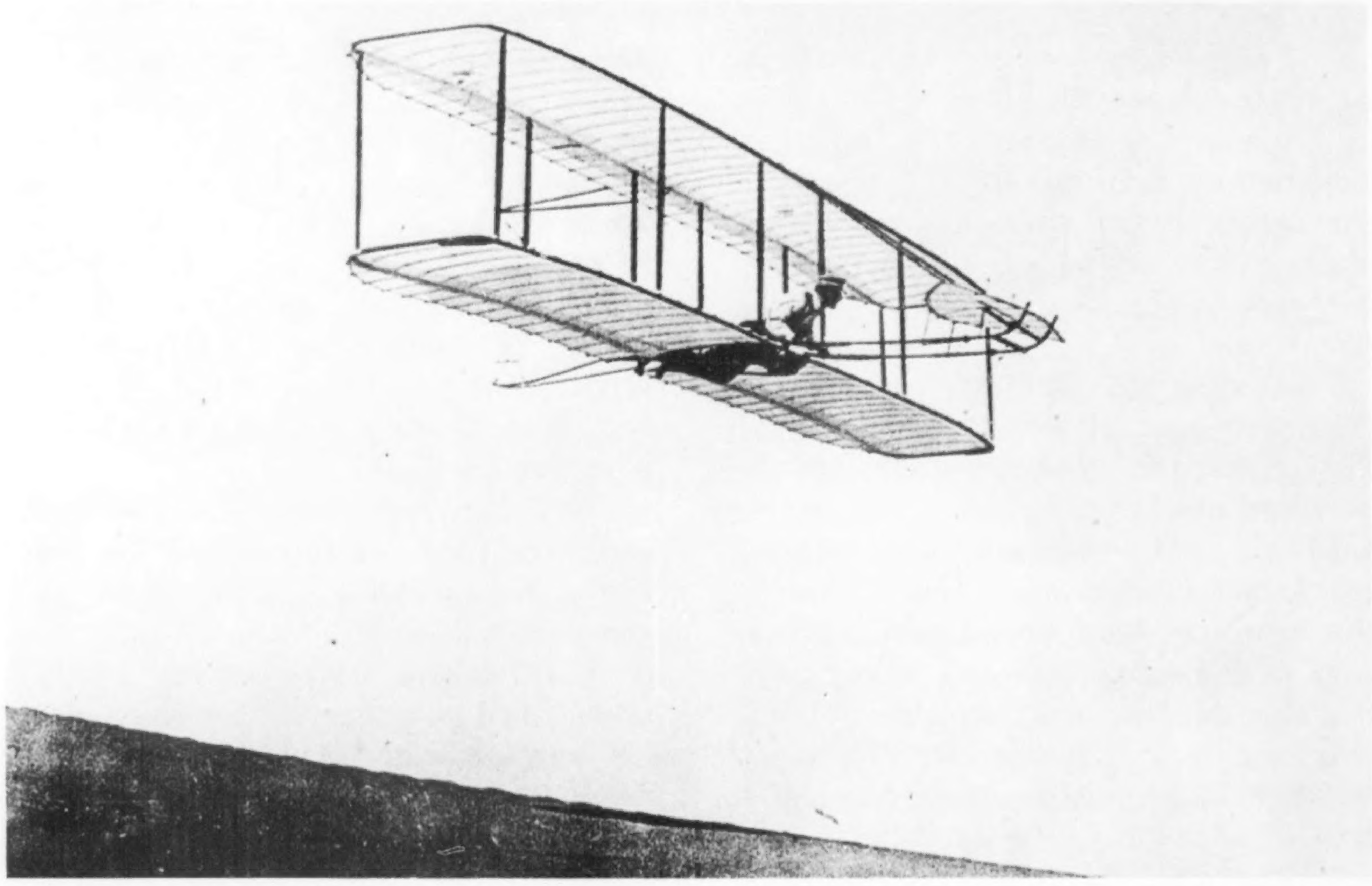
Orville being launched for a flight in the 1902 (modified) glider; Wilbur at right; Dan Tate is at left.

The elder brother now suggested that the men "not look too sad, but . . . laugh and holler and clap . . . hands and try to cheer Orville up when he started." Wilbur then took up a position by the right wing tip, replacing a low wooden bench that had supported it up to this point.

At 10:35 Orville moved his right hand toward his left and the craft began to move slowly into the 44 kmph (27 mph) wind. Wilbur had little trouble keeping up with the slow forward speed of the machine. As it rose into the air after a 12 m (40 ft.) run, Daniels clicked the shutter just as everyone broke into cheers on cue.

The airplane rose and fell erratically as it sailed forward. After 12 seconds of flight it struck the sand at a point about 120 feet from where it had left the rail. It hadn't taken very long and the machine hadn't traveled very far, but it had undeniably risen from the ground and flown forward under its own power, landing at a point as high as that from which it had taken off. On this isolated North Carolina beach, a man had flown.

The small crew carried the aircraft back to the rail for a second trial, then retired to the shed for a bit of warmth. At 11:20 the group emerged from the building and Wilbur took his place on the machine for a flight 23 m (75 ft.) longer than the first. Twenty minutes later Orville made his second trial, which lasted 15 seconds and covered a little more than 61 m (200 ft.). About noon Wilbur tried again, turning in the best performance yet, a spectacular 260 m (852 ft.) in 59 seconds.



". . . Damned if they ain't flew!" The 1902 Wright No. 3 (modified) glider just after launch from the dunes at Kitty Hawk in its second and final form, with a single rear rudder.

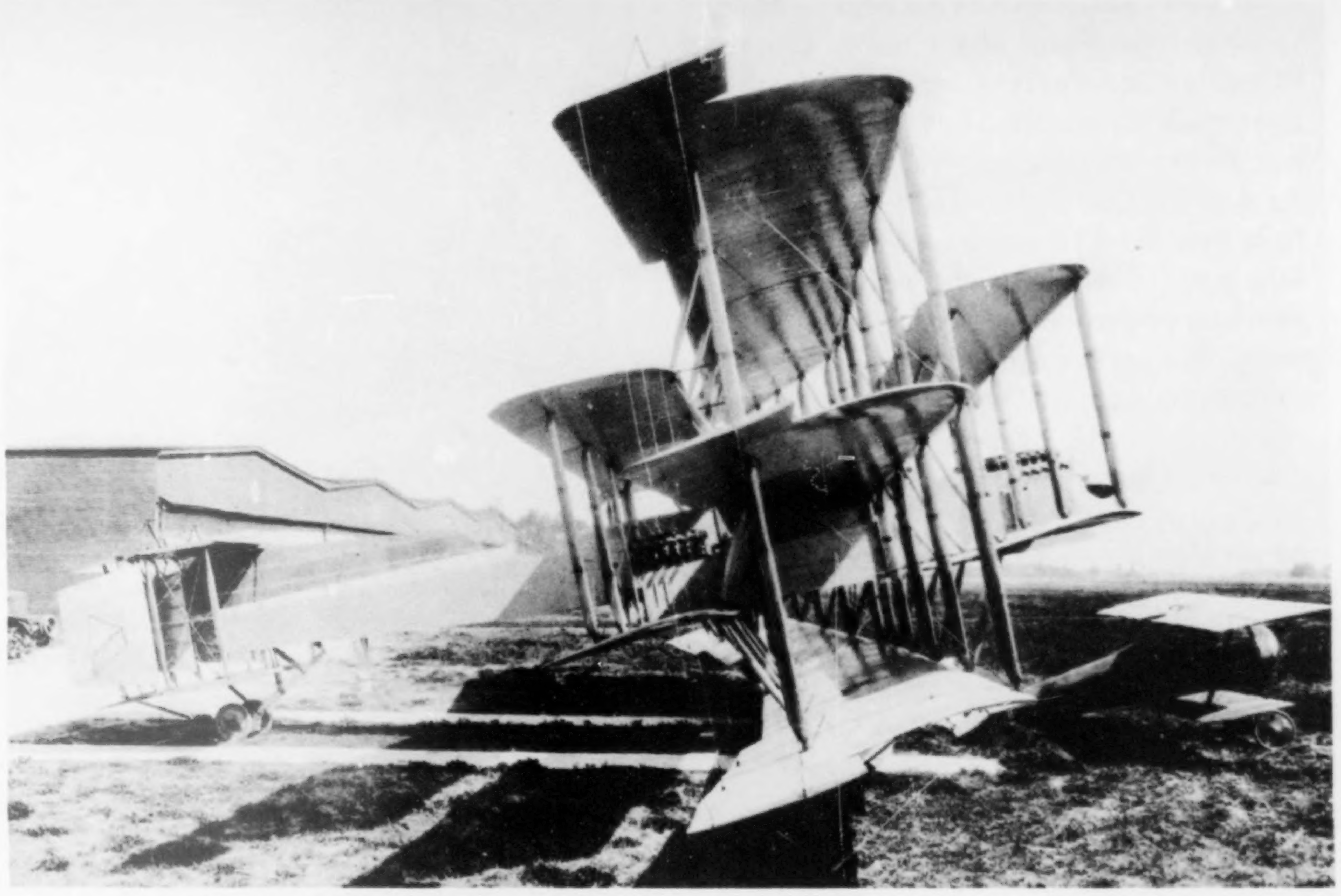
The men carried the airplane back to camp. As they clustered around it, a gust of wind sent the machine tumbling. Daniels went head over heels through the wood and wires, suffering severe bruises. The airplane was extensively damaged. The witnesses helped drag the wreckage into the hangar and returned to the station. One of them then raced down the beach toward Kitty Hawk. When he encountered Tate, in whose home the Wrights had lived during their first experiments, he was yelling excitedly, "They have done it! They have done it! Damned if they ain't flew!"

The Wrights ate an unhurried lunch, then strolled up to Kitty Hawk to confirm the reports of their success with old friends in the village, but not before sending a telegram to their father. The message, slightly garbled, was received in Dayton at 5:25 that evening:

> Success four flights thursday morning all against twenty one mile wind started from Level with engine power alone average speed through air thirty one miles longes 57 seconds inform Press home Christmas. [sic]
>
> —Orvelle Wright.

Ingenious Wings

Walter J. Boyne
Assistant Director, NASM



1920 Johns Multiplane. Inventors concluded if 2 wings were good, then 4, 5, 6, or 7 would be better. Giants such as Johns' Multiplane made a short skip off the ground and crashed.

For poets and artists, wings have always symbolized flight. This romantic inspiration also provides the background for an interesting look at how engineers and inventors have worked to create new aircraft designs.

Engineers respond in pragmatic ways to particular requirements, while inventors seek extravagant, even colorful approaches to fulfilling the same needs. The methodical engineers usually take longer and are more successful than the inventors, but the inventors usually have more fun.

The reasons for the concentration on wings are at once obvious and subtle. Wings are the basis of flight in that they create most of the lift that sustains a conventional aircraft, and variations in wing size, shape, and disposition greatly affect an airplane's performance. However, wings have many uses unrelated to their lifting function: some serve as space for passengers, fuel, and cargo; some are also the strength of the aircraft and may contain landing gear, lighting equipment, and armaments. In some designs, notably the flying wings of Northrop, Lippisch, and Horten, the wing *is* the aircraft.

Throughout the history of flight, virtually every wing configuration has been tried. Before the Wright brothers, most aircraft were conceptualized as monoplanes, often in configurations of birds in flight. Prof. Samuel P. Langley studied the birds; both his successful models and his unsuccessful full-size aircraft were monoplanes. The difference between his successes and failures, as would often be the case in the future, was the relationship of size to structure. The materials of the day were strong enough for his models but not for his full-scale aircraft.

The Wright brothers, familiar with Octave Chanute's biplane kites, perceived that a biplane configuration would lead to an aircraft of sufficient wing area to sustain the weight of the aircraft, pilot, and engine. Only a biplane with its bridge-girderlike construction and available materials could be made *strong* enough and *light* enough.

Once the Wright brothers had proved to the disbelieving world that flight was possible, a proliferation of wing types evolved, which followed three general patterns. The conservatives opting for biplanes like the Wrights', sought improvements in power plants, controls, and airfoils. More liberal innovators, notably Bleriot, continued to experiment with monoplanes aiming for improved performance and strength. The radical inventors, seeking a "great leap forward" over the Wrights, went to multiple wings, round wings, venetian blind wings, square wings, and barrel wings. This trend has continued as engineers work toward sound new designs that meet new performance needs on a step-by-step basis, and inventors and romantics seek faster, more spectacular solutions.

Engineers respond to stated needs by examining what has been done in the past and determining what new principles may be applied. For example, if an engineer of the 1920s was required to build a bomber with a greater load, he would seek a more powerful engine and devise larger, broader wings of an airfoil that would generate more lift. Thus, a Martin GMB would develop into a Curtiss Condor. The inventor, by contrast, would leap to other conclusions: if 2 wings were good, then 4, 5, 6, or 9 would be better. Instead of a gradual increase in size, giants such as the Barling Bomber or Johns Multiplane would appear—briefly.

As engineering knowledge developed, it became obvious that monoplanes could be built strong enough to gain the advantages of reduced drag. Perhaps the earliest and most convincing example of this is the Fokker D. VIII design of Reinhold Platz. This aircraft, which appeared at the end of World War I, was a clean-lined monoplane that had high performance for its relatively low-powered 110-horsepower engine. It had a thick cantilever wing that was so different from anything being used by the Allies that it was the subject of many unsolved engineering analyses.

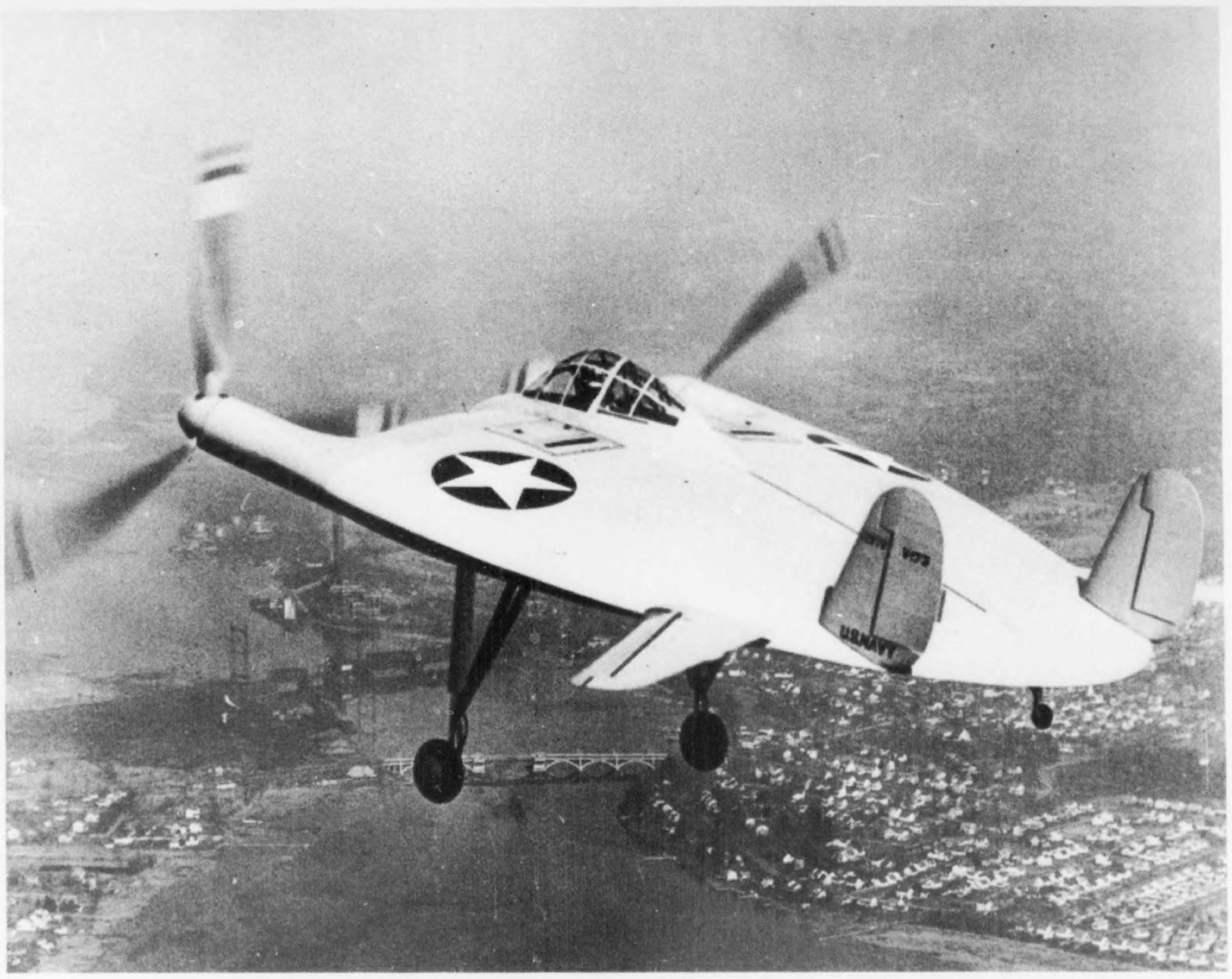
The Fokker D. VIII was the precursor of the new era, but before the monoplane was universally adopted, there was a period of almost 20 years in which biplanes were gradually phased out. Thus most air forces of the world through 1935 were equipped with biplane fighters and bombers.

The same general status was true of civil and commercial aircraft; monoplane airliners became prevalent only after 1935 and the introduction of the Douglas DC-3. But during this period, the inventors were still at it. Speed was sought by reducing the span or area of the wing in flight or by physically changing from a biplane to a monoplane. Makhonine, a Russian engineer in France developed an aircraft with outer wing panels that were run out on rails; on takeoff, the wings were extended to their full length, while in flight they could be "reeled in" for higher speed. In Russia, the Nikitin Sevchenko appeared, a biplane whose lower wing was hydraulically retracted to fit into recesses in the fuselage and upper wing; the plane transformed itself from biplane to monoplane in flight. (The British later experimented with the Hillson slip wing. A droppable wing was mounted on a Hurricane fighter, biplane fashion; after it was catapulted off a ship, the wing was "slipped," and the biplane became a monoplane again.)

In almost all cases, the inventor became so fascinated with his idea that he disregarded such matters as complexity, weight, and maintenance. And while his basic idea might have worked, the aircraft employing it was usually a dog.

The 1930s were replete with these brave adventures: there was the Albessard Triavion, a throwback to Langley's tandem wing and the Custer Channel Wing, an interesting application of the Bernoulli principle that really worked but never quite as well as was claimed. And, with the biplane/monoplane question resolved, a series of experiments was conducted with the relationship of span to chord—the aspect ratio of the wing. Aircraft evolved with very long, narrow wings, of the type that are now associated with gliders, as well as aircraft with very short, broad wings. The latter appeared in fair numbers: the Arup, Zimmerman, and others. Of all of these, only the Vought VS-173 *Flying Pancake* had any measure of success.

While all these variations were underway, the engineers continued refining wings model by model, improving the airfoils and the finish, and in general creating a generation of high-performance aircraft. The next big challenge was compressibility, the result when a wing of standard design moves so swiftly through the air that the disturbance of the molecules creates what popularly and incorrectly became known as "the sound barrier."



During experiments with the relationship of span to chord, aircraft such as this 1942 Vought V-173 Flying Pancake *were developed. It was one of the few aircraft of this design that had a measure of success.*

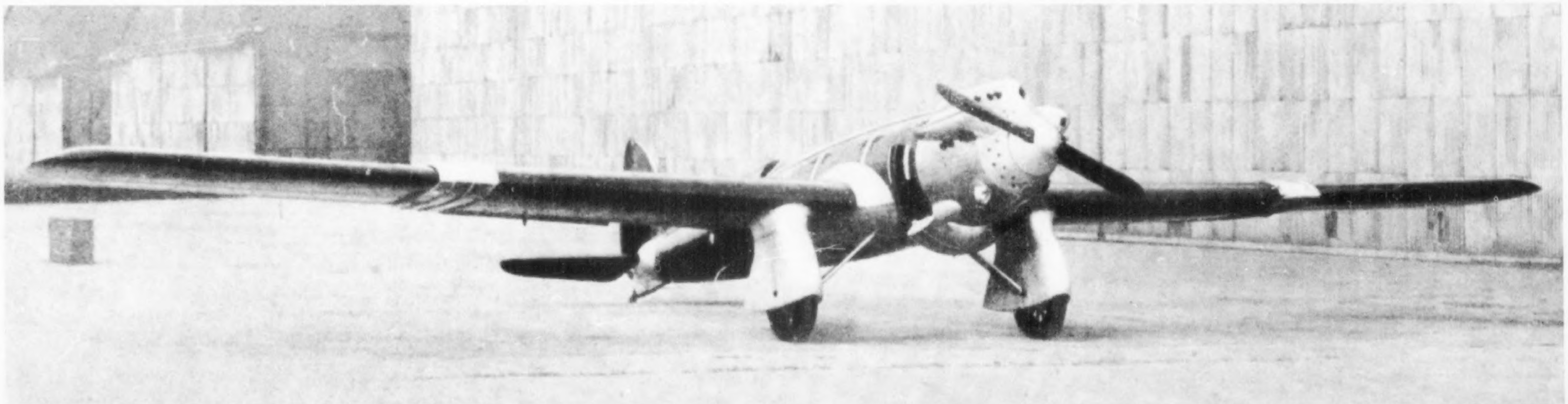
World War II fighter planes began to encounter the compressibility problem in dives; the aircraft would suddenly vibrate, shudder, and jolt, and the controls would become ineffective. There was unfounded fear that the speed of sound, at which the compressibility became most pronounced, would prove to be some sort of impenetrable barrier. The engineers already had a solution: make thinner wings and sweep their leading edges back. The idea had originated theoretically in Germany in 1935, by Dr. Adolf Buseman, and later in the United States by Dr. Robert T. Jones. The concept was applied in combat, however, in the first operational jet plane, the German Messerschmitt Me 262, which had swept wings for structural reasons, yet it inadvertently reaped the aerodynamic benefits incident to the sweeping.

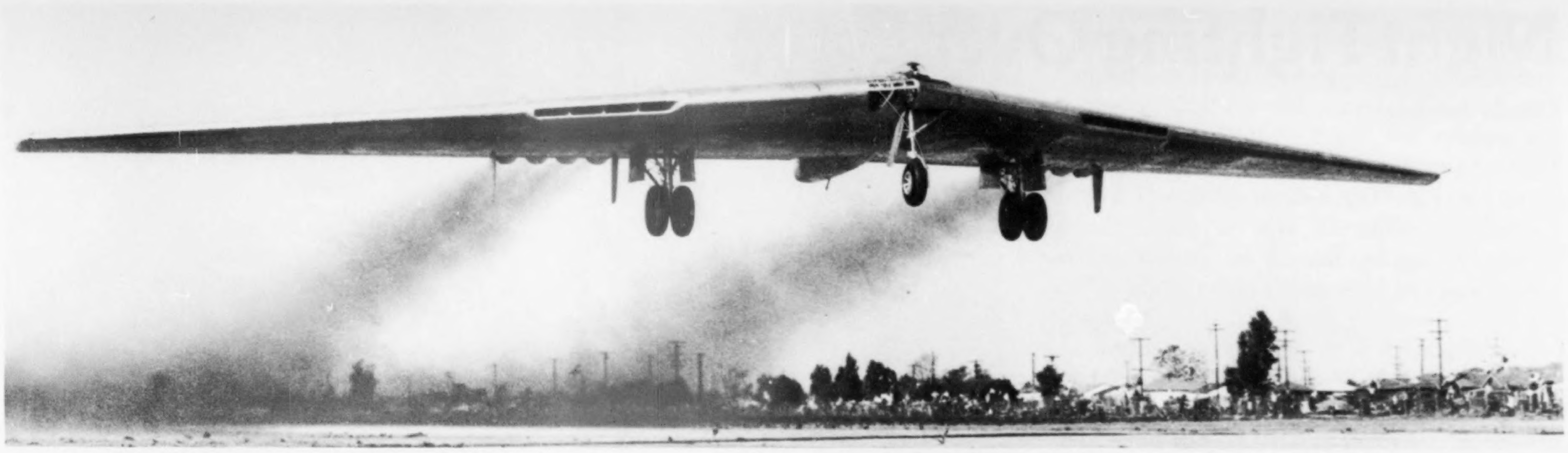
Swept wings became the avenue to supersonic speeds, but even while conservative engineers were busy revising their concepts, there were three other groups that had been pursuing another area of investigation. In Germany Dr. Alexander Lippisch was concentrating on flying wing aircraft, which culminated in the rocket-powered Messerschmitt Me-163 fighter. Also in Germany, the Horten brothers were pursuing a flying-wing but of different design. Lippisch preferred a lower-aspect ratio, which ultimately culminated in delta-winglike shapes, while the Hortens preferred the gliderlike high-aspect ratio. The Me-163 was produced in quantity—more than 350 were built—and a Horten-inspired fighter, the Gotha Go-229, was in production at Friedrichsrode when the factory was taken by American ground forces.

In America, the late Jack Northrop, famous for many pioneering designs such as the Lockheed Vega and Northrop Alpha, was the leading proponent of the flying wing. Northrop's experience was perhaps the most satisfying but also the most embittering. His ideas were sufficiently proved to gain production orders for a jet reconnaissance bomber, the YB-49, but a crash during a test flight and alleged political difficulties resulted in cancellation of his contract. Flying-wing development came to what may be only a temporary end, for freighters (450,000 kg; 1,000,000 lb. gross weight) of the future may well be "span-loaded wings." (And it is interesting to note that the proposed "stealth bomber" may be a flying wing.)

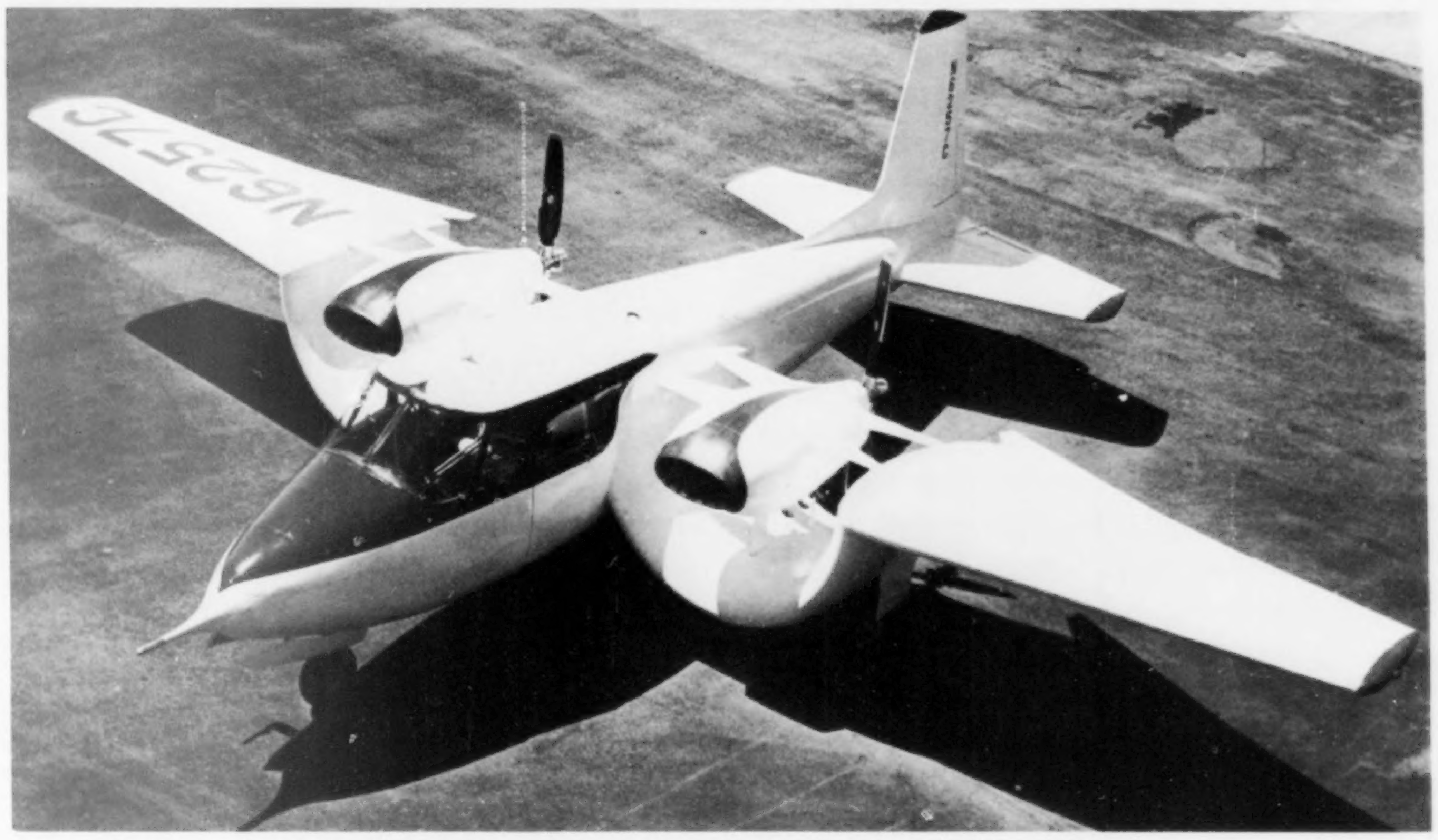
With the sophistication of swept wings and with their evolution into both delta and "swing wings"—which can be converted from straight to swept configuration in such fighters as the General Dynamics B-111, Grumman F-14, and Panavia Tornado—it might be thought that the conservative engineers have finally prevailed, and that there is no more room for the liberals and the romantics who had made winged flight so colorful. In the new golden age of flight, which has been spawned by

Makhonine developed this 1931 aircraft with outer wing panels that were run out on rails. On takeoff the wings were extended to their full length, while in flight they could be "reeled in" for higher speed.





1947 Northrop YB-49 flying wing on the first flight from Hawthorne to Muroc, Oct. 21, 1947. A crash during a test flight and alleged political difficulties resulted in cancellation of Northrop's contract for this jet reconnaissance bomber.



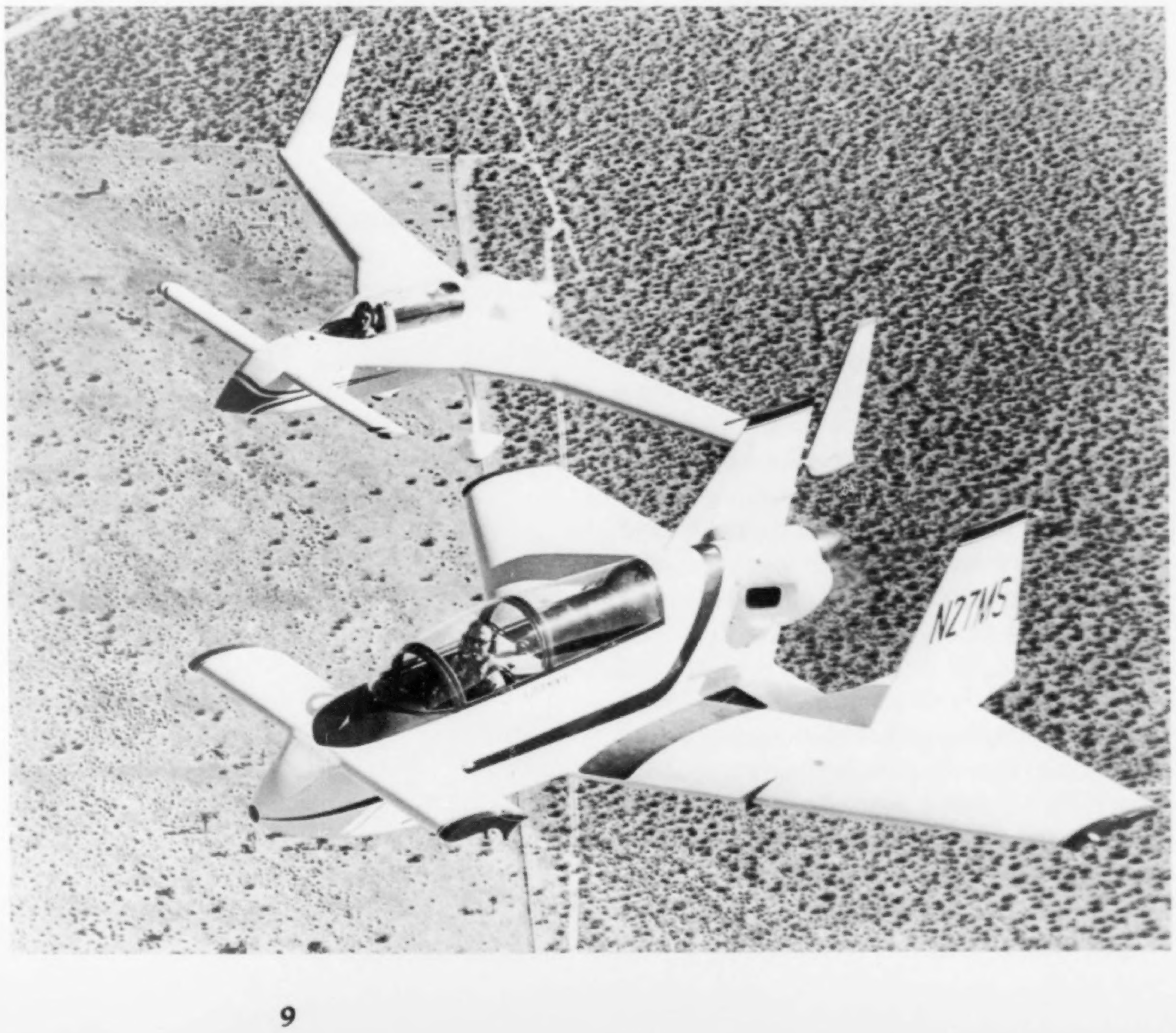
1953 The Custer CCW-5 Channel Wing was an interesting application of the Bernoulli principle that worked but never reached production status.

American homebuilders, one can still see every configuration, from Deltas to tandems to rotors. New wings, new airfoils, new construction methods, and new configurations are appearing across the country, and there is one design group that may well have revolutionized the shape and size of general aviation aircraft. In California, young engineer Burt Rutan has developed a whole fleet of fuel-efficient aircraft with slim tandem wings that have an almost eerie, insect-like beauty.

The Rutan story began with what became a movie star, the VariViggen, which appeared in the science-fiction thriller *Death Race 2000.* Next came the VariEze, a pencil-slim tandem wing two-placer, which flashes through the sky like a demented dragonfly and is being built by the hundreds at homes throughout the country. In rapid order came the Quickie, an 18-horsepower tandem wing, (210 km/hr–130 mph) single-place aircraft that set new standards of efficiency; and perhaps the most significant of all, the twin-engine 4-seat Defiant, a tandem wing that again promises to be the general aviation solution to the fuel shortage.

It is probably appropriate that Rutan, the young genius of new construction methods, and R.T. Jones, the senior engineer who formulated the concept of wing sweep, have joined forces to create the NASA/Ames AD-1 oblique-wing research aircraft. This jet-powered aircraft has a pivoting wing, which is straight for takeoffs and landings but turns diagonally for supersonic flight. Now undergoing tests, this radical new aircraft may presage future supersonic transport designs and is a happy combination of engineering and invention. ■

Burt Rutan's fuel-efficient aircraft: Rutan's 1972 VariViggen, foreground, appeared in the science-fiction thriller Death Race 2000 *and was the first of his long series of innovative planes. The 1975 VeriEze is a tandem wing two-placer being built by the hundreds at homes throughout the country.*



Night Fighting Over Europe

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Night fighting began in response to night bombing. In January 1915 German Zeppelins began night bombing attacks on England. The British tried to intercept them with fighters, but poor fighter performance and an almost total absence of detection equipment proved to be a great handicap. It was six months before the first Zeppelin was destroyed and that was by air-to-air bombing. By mid-1916, the combination of ground searchlights and higher performance fighters caused such great losses that Zeppelin raids were virtually abandoned, and the Germans began using Gotha and Giant bombers to attack England.

To combat the German bombing, the British set up a Home Defense Force using sound detectors, searchlights, ground observers, and trained pilots equipped with better aircraft. Diverting the British forces from the Western Front back to England was a primary goal of the German raids that backfired on the Germans. By prompting the British interest in air defense, the Germans helped the British to defeat them in the Battle of Britain.

The British established a grid system of numbered and lettered squares covering southeast England. Raids were represented by markers moved along the grid table. The system was sound in conception, but it was fatally handicapped by the lack of ground-to-air communication.

The Germans, too, set up a rudimentary air-defense system using antiaircraft guns, searchlights, and trained pilots. The first night-fighter victory was in February 1917 when a German 2-seater shot down two Allied bombers as they were landing after a raid, presaging the intruder tactics of the next world war. With more available targets, the German fighters had fairly good results, and at least one pilot scored five night victories.

The French also established a night-fighter force to combat the regular raids by the German Gotha bombers. A British night-fighter squadron based in France destroyed 21 German bombers during a 4-month period late in 1918.

By the end of World War I, Germany, England, and France had all developed night-fighter systems as advanced as they could be considering the lack of reliable communications and good detection systems.

Not much was done to further develop the tools and techniques of night fighting until a few years before World War II. Germany, of course, was prohibited from developing an air force by the terms of the Treaty of Versailles. However, even when the Luftwaffe had come "out of the closet" in the early 1930s only cursory attention was given to night fighting; the Germans felt that their excellent flak (antiaircraft) guns were all that were needed to defend themselves against night bombing.

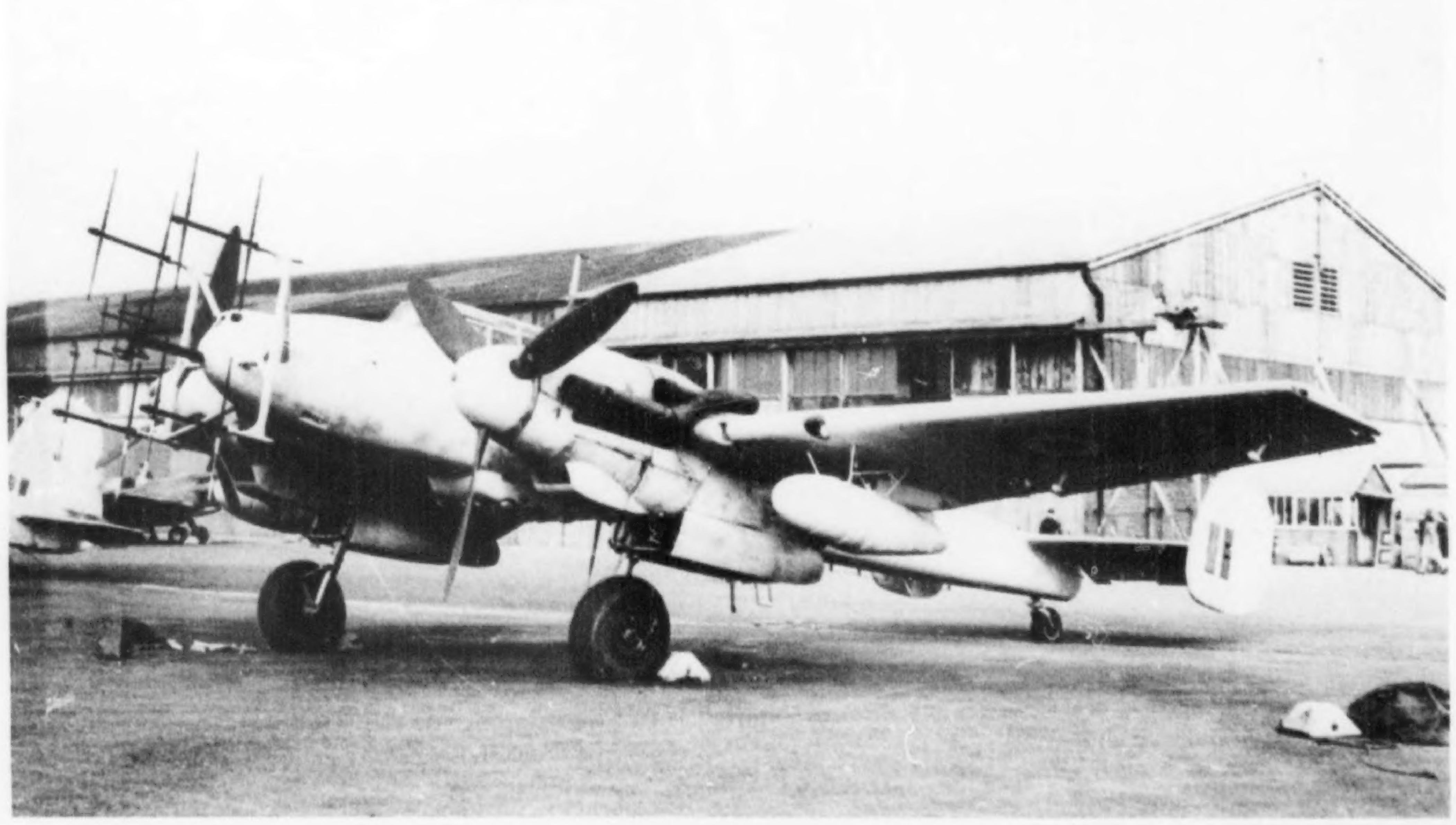
Between the World Wars, the "boffins," as the British call their scientists, had not been idle. By the beginning of the 1930s all of the required technology for the development of radar was available.

Radar (*R*adio *D*etection *A*nd *R*anging) is a device that provides information on the location of objects by transmitting electronic emissions and receiving the portion of the emissions reflected from the object. By measuring the direction of the return signal and the elapsed time between sending and receiving the pulse of energy, the direction and distance of the target can be determined. By keeping track of the sequential positions of the target, its course and speed can be computed. The information received is presented to the radar operator, ground or air, on cathode-ray-tube (CRT) scopes (similar to television screens). With early radar, much skill was required to interpret the display and to direct the fighter into the proper position relative to the bomber. As radar systems developed, the combining of ground-based radar (GCI-Ground Control of Intercept) and airborne radar (AI-Airborne Interception) made intensive night fighting possible.

By 1936, the British had developed ground-based radar systems that could detect an aircraft more than 161 km (100 mi.) away. A chain of these systems was set up as a warning and fighter-control net for the defense of England. They used a relatively long wavelength and were accurate only to within several miles. (The lack of tight discrimination in the long wavelength radars can be compared to the difficulty of trying to pick up a needle while wearing boxing gloves. Shorter wavelengths give greater discrimination and accuracy.)

At about the same time, radar was being developed in Germany at the Freya and Würzburg ground stations. The Freya system was an early-warning

1943 Messerschmitt Bf 110 G-4/R2 with nose radar antennas and engine exhaust dampener directed over the wings.



set and could not determine altitude; the Würzburg system was used to control the flak guns.

The British realized that although their Ground Control Intercept (GCI) system was satisfactory for daylight operations, since targets could normally be seen visually for 8 km (5 mi.) or more, the GCI would be inadequate at night or in bad weather when the targets could not be seen for more than a few hundred meters (yards). By mid-August 1937, the first airborne radar was flight-tested. In 1939 the first practical Airborne Interception radar was tested in a Fairey Battle, and later that year, on the eve of World War II, 21 Bristol Blenheim long-range fighters were equipped with it. Throughout the War, the British continued to develop AI radar with shorter wavelengths that was more accurate and effective.

Both the Luftwaffe and the Royal Air Force (RAF) used 2- or 3-man crews in their night fighters—a pilot, a radar operator, and sometimes a gunner. Usually a Luftwaffe night-fighter pilot received direction, speed, and altitude instructions by radio from the GCI station. In the latter stages of an interception, the pilot would be guided by spoken instruction from the radar observer huddled over his AI set until the pilot could see the target at close range.

Neither the Germans nor the British developed aircraft specifically for night fighting but rather modified existing aircraft or those under development. Desired characteristics of a night fighter include good acceleration and deceleration to allow the pilot to synchronize his speed with that of the target; sufficient speed to overtake the target rapidly; heavy armament to destroy the target quickly; good visibility; and enough interior space to mount the radar equipment. In addition, long range and endurance were as highly desired then as they are today.

The Luftwaffe bombed England during The Blitz of 1940 almost at will, while the British night fighters and antiaircraft guns were virtually ineffective. The night fighters were radarless day fighters controlled by the Chain Home early-warning radar, which was not designed for controlling intercepts. The fighters could only be advised of the general location of the bombers. The interceptors were successful in only a few instances when the Moon was full or when the bombers were low enough to be illuminated by the searchlights.

The radar-equipped Beaufighters became operational in September 1940 and more were built in the following months. Improved AI radar sets were installed, and along with the British-developed GCI radar, they provided the guidance required for successful night-fighter operations. (Inspection was still visual but was made much easier because the AI radar brought the fighter into close range.)

With this new combination, the effectiveness of night air defense increased markedly. The night fighters' (primarily the heavily armed Beaufighters') scores began to mount. In the first two months of the Blitz, the RAF night fighters shot down only eight bombers out of 12,000 enemy sorties. They shot down 22 in March 1941, 48 more in April, and 96 in the first two weeks of May. The Blitz ended that month because most of the German bombers were moved to Russia, although sporadic night raids continued throughout the war.

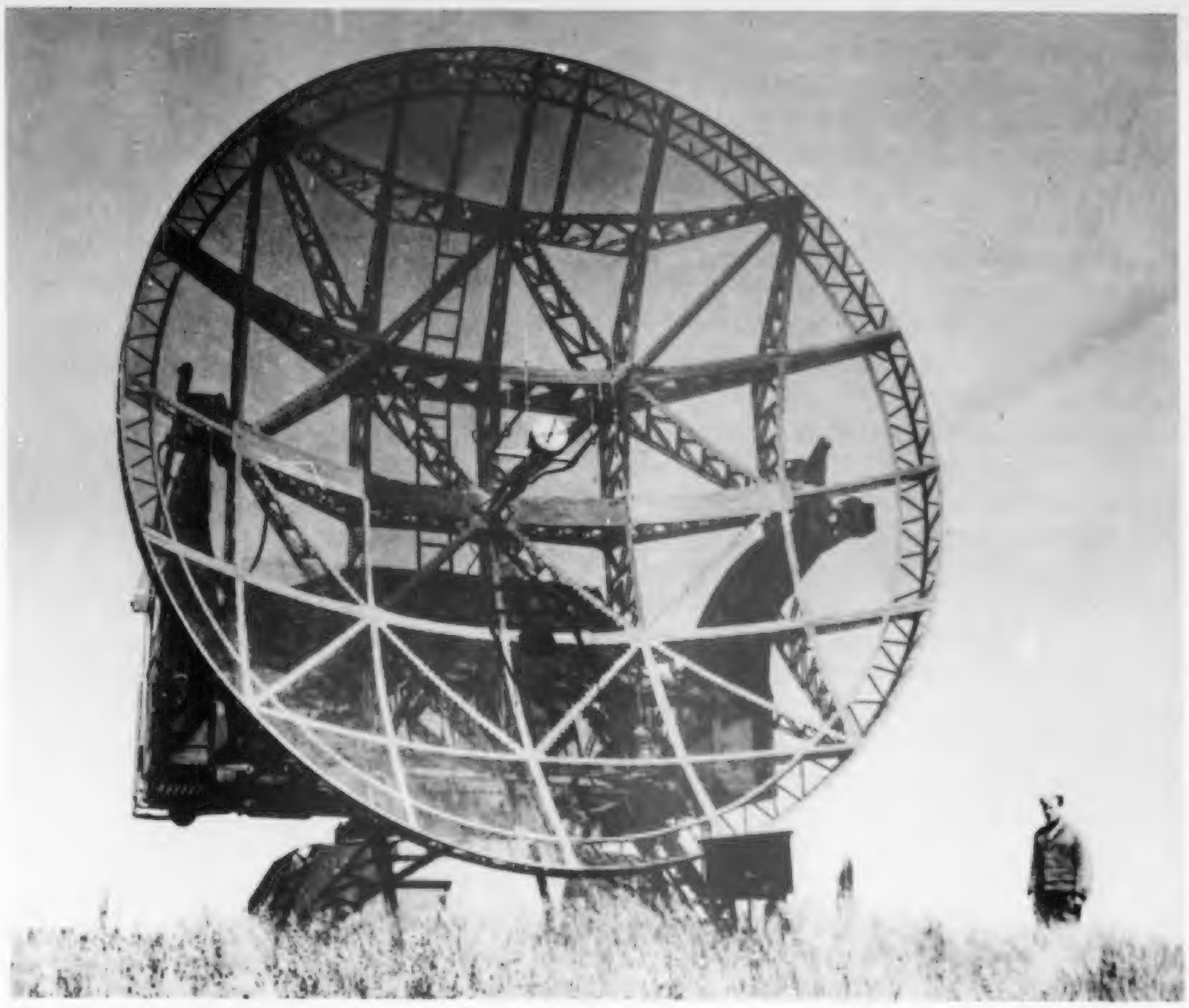
Most night combat in World War II occurred against the RAF night bombers during the Battle of Germany. It could be called the "Battle of Boffins" as each side evolved new techniques and equipment to gain advantage, usually temporary, over the other.

In July 1940, the Germans began to organize a night-fighter force. Before then, they had depended upon their excellent radar-directed flak. At first, radarless fighters were directed to the bombers by the Freya early-warning radar and by searchlights.

The Würzburg flak-control radar was adapted for use as a GCI radar, but as its range was inadequate, a new model, the Giant Würzburg, was developed. With this radar the Luftwaffe set up a defense system called Himmelbett (4-poster bed), dividing the airspace from Denmark across the north of Germany and France and down to Switzerland into about 750 boxes, each about 32 km (20 mi.) wide. Each box contained a Freya early warning radar and two GCI radars. The GCI radars could also direct the searchlights in each box onto the target. This defense array was popularly known as the Kammhuber Line, after its organizer, Maj. Gen. Josef Kammhuber, Commander of Luftwaffe Night Fighters. The system was basically successful until 1942, when the RAF began large-scale raids that saturated the capabilities of the Himmelbett boxes. The Germans' Lichtenstein AI radar was introduced at about this time. Their efficiency in destroying RAF bombers markedly increased.

As the electronic war continued, the Germans developed both ground and airborne receivers that allowed them to track and home in on the emissions from the RAF H2S bombing radar carried in many of the heavy bombers.

To augment the Himmelbett, the Luftwaffe sent radarless single-engine fighters to the vicinity of target cities to spot bombers visually, both in the glow of the fires on the ground and in the beams of searchlights. This technique, called "Wild Sau" (Wild Boar), was quite successful during 1943. At that time, the RAF introduced Window, a method of jamming or spoofing the enemy radar by dropping foil strips cut to one-half the wavelength of the German radar. In the July 24, 1943, Hamburg raid, nearly 850 bombers released more than 92 million foil strips causing total confusion among


Wurzburg radar with Freya attachment used in Germany to detect enemy bombers and used to direct fighters to the bombers for interception.

the defenders. Only 12 bombers were lost, mostly to Wild Sau fighters that were not affected by the Window.

Another RAF jamming method was the transmission of intense noise on the German night fighter/GCI voice frequencies. Without voice communication, the RAF bombers carried transmitters in the engine compartment, using the engine noise to drown out voice transmissions.

Also, the British used German-speaking airmen to broadcast false instructions to the night fighters. When the Germans switched to women broadcasters, the British promptly countered with German-speaking women.

The British sometimes added insult to injury by transmitting recordings of Hitler's speeches over the night-fighter control frequencies. Can you imagine trying to fly a fighter at night with one hand raised in the Nazi salute?

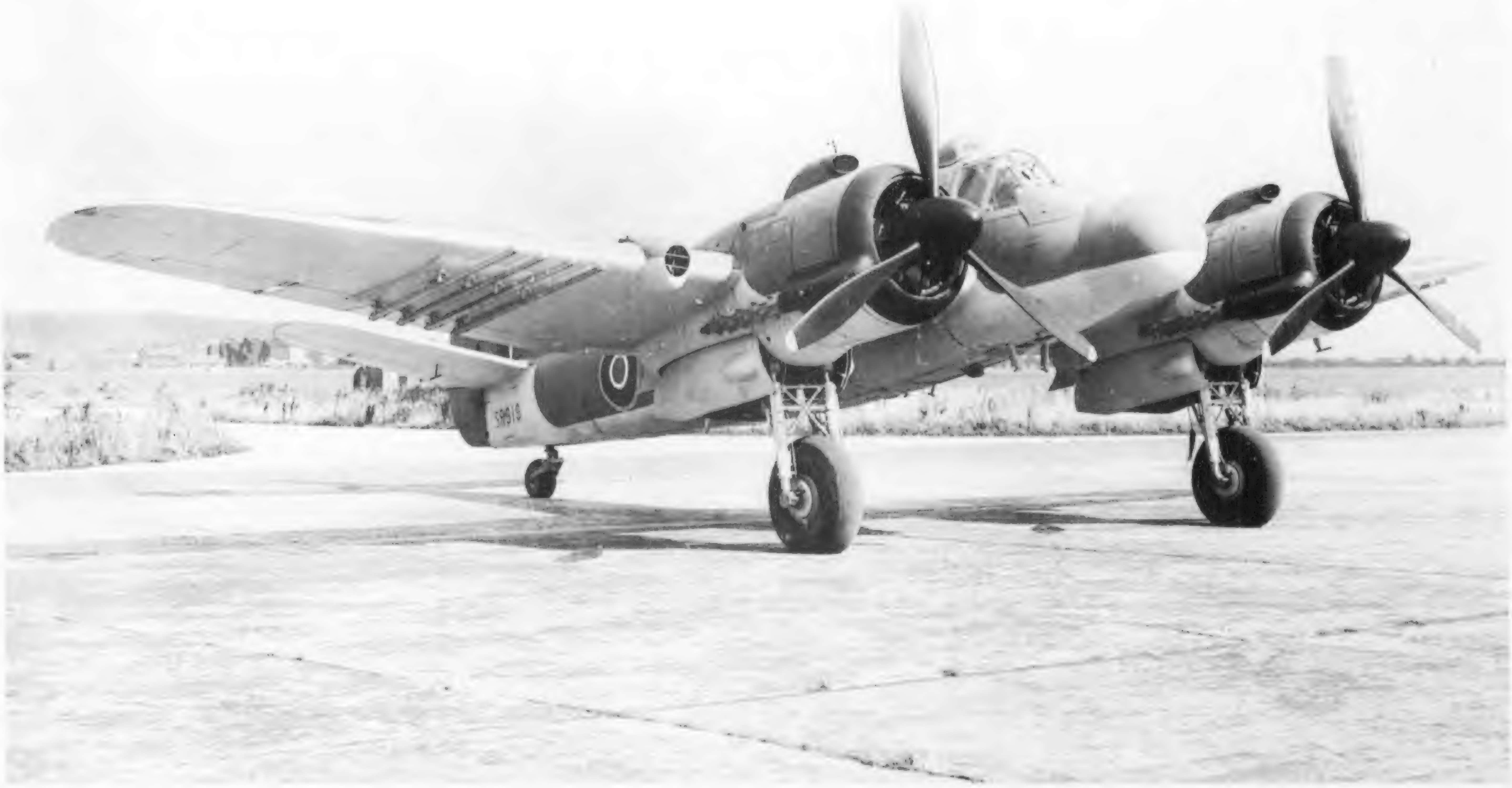
The Germans had developed a system of transmitting control information to the fighters by a teletype-like device, but the war ended before it became operational. Two other innovations did, however, aid them in bomber attack. Flensburg was a passive electronic device carried on the night fighters that received the signal from Monica, the RAF's tail-warning radar. Using Flensburg, the Luftwaffe fighters could locate and track bombers from more than 161 km (100 mi.) away. The British did not discover this until a Flensburg-equipped Ju88 accidentally landed in England. The armament innovation was *Schräge musik* (slanted music), the cannon on the German night fighters that inclined upward at 60 to 70 degrees, allowing the fighter to remain below the bomber. In this position, the bomber was visible to the fighter, but the fighter was barely visible and out of the gun coverage of the bomber.

The Mosquito, used as a night intruder, helped by joining the British bomber streams to shoot down the German night fighters. The Mosquitos used both AI radar and Serrate, a passive receiver that could track signals from the German's Lichtenstein AI radar. By summer of 1944, the Mosquitos often outnumbered the German night fighters.

Despite all this, the German night fighter force remained a potent enemy, destroying more than 5500 RAF bombers. In fact, in early 1944 the Luftwaffe night fighters came close to defeating the RAF Bomber Command. Because of excessive losses, the RAF abandoned their massive attacks on Berlin and other cities. The loss rate was greater than 5 percent—more than 1000 bombers were lost—and more than 1500 additional bombers were damaged. On the Nuremburg Raid on March 30, 1944, out of 795, the RAF lost 94 bombers with 71 damaged. The casualty rate in Bomber Command was the heaviest of any British service in the war. That the German night fighters were eventually defeated was due largely to the daylight attacks by the USAAF and by the shortage of fuel caused by round-the-clock bombing of Germany.

One of the positive outcomes of the war was the outstanding technological advances achieved. Through ingenious thought and innovativeness, radar systems grew and developed. But, although the war at night was largely a matter of technological measures and countermeasures, it was marked by the great skill and courage of the aircrews on both sides. ■

Radar—(Radio Detection And Ranging)—a device that provides information on the location of objects by transmitting electronic emissions and receiving the portion of the emissions reflected from the object.
Ground Control Interception (GCI)—ground-based radar.
Airborne Interception (AI)—airborne radar.



Bristol Beaufighter 1945, one of the first successful British night fighters, with a radome nose and exhaust gas diffusers.

The Triumph of Apollo 13

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Department of Space Science and Exploration, NASM

Anticipation mounted for the flight of Apollo 13, and there was every indication that it would be as spectacularly successful as the two previous lunar missions. Although one heart-stopping moment had occurred on Apollo 12. The spacecraft's main electrical power momentarily failed only 36 seconds into the launch due to an unexpected artificial lightning bolt created inside the rocket from static electricity as the Saturn V lifted through a rainy overcast.

By contrast, Apollo 13 was launched in calm, beautiful skies and promised to be the most scientific yet. The planned landing site on Fra Mauro Highlands represented a cross section of lunar history. For the first time the astronauts took a drill along to extract a core sample from up to 3 m (10 ft.) beneath the Moon's surface. Selenogists on Earth hoped to be able to examine rocks and soil from four different ages of the Moon.

Apollo 13 also carried another new and significant piece of equipment, a Lunar Heat Flow Experiment, used to measure the heat inside the Moon as well as its surface to determine whether the Moon is gradually heating or cooling. The heat probes were to be sunk into two 3 m (10 ft.) holes made by the drill. More time was also to be spent on the lunar surface to conduct the experiments and to take high resolution pictures with a brand new topographic camera. The mysterious solar wind (gases ejected from the Sun's surface at great speed) would be measured in interplanetary space by a new instrument called the Solar Wind Composition Experiment.

Apollo 13's commander, Navy Capt. James A. Lovell, Jr., was this country's most experienced astronaut, though his crew—civilians Fred W. Haise and John L. "Jack" Swigert, Jr.—were rookies. Lovell had orbited the Earth for 14 days in Gemini 7, logged almost 4 additional days in Gemini 12, and spent 6 1/2 days going to and around the Moon on Apollo 8.

The Apollo 13 mission had been flawless until the evening of the third day. The first inkling of any trouble aboard the complex multi-ton spacecraft was an unaccountable bang. *Odyssey*, the Command Module, with *Aquarius*, the Lunar Module, attached, was 332,500 km (206,000 mi.)—about 4/5 of the way to the Moon—from Earth. The clocks at the Manned Mission Control Center in Houston officially recorded 13 hours 13 minutes of the Apollo 13 mission on April 13, 1970.

As Captain Lovell later recalled of this frightening moment: "Fred [Haise] was still in the Lunar Module. Jack [Swigert] was back in the Command Module in the left-hand seat, and I was halfway in-between, in the lower equipment bay, wrestling with TV wires and a camera—watching Fred come on down—when all three of us heard a rather large bang—just one bang. Now before that . . . Fred had actuated a valve, which normally gives us that same sound. Since he didn't tell us about it, we all rather jumped up and were sort of worried about it; but it was his joke, and we all thought it was a lot of fun at the time. So when this bang came, we really didn't get concerned right away . . . but then I looked up at Fred . . . and Fred had that expression like it wasn't his fault. We suddenly realized that something else had occurred . . . but exactly what we didn't know."

Seconds later, a master alarm sounded and after a sudden surge of power, the main electrical system was out. Lovell glanced out the window and saw some precious liquid oxygen (LOX), venting out of the rocket's side as gas. He looked at the gauges. One of the Lox dials read zero and the other was dropping fast. Lovell immediately radioed Houston: "Hey, we've got a problem."

Calmly, the mission commander briefly explained what had happened: "O.K. Houston, we've had a main B bus undervolt . . ." Haise added ". . . and we had a pretty large bang." (An undervolt meant a sudden loss of power in one of the spacecraft's two main electrical circuits).

Hundreds of ground controllers in Houston and thousands of technicians and scientists throughout NASA worked feverishly to solve the most urgent problem yet faced in the history of U.S. manned spaceflight. Millions more around the world shared those terribly anxious 3 1/2 days for the lives of the three spacemen. Many people openly prayed and wept.

Soon after Captain Lovell's alert to Houston, it was discovered that two of the Service Module's three fuel cells that were vital to the mission had shut down. These cells combine oxygen and hydrogen to produce electrical power and potable water. Part of the oxygen was also used by the astronauts to breathe. Houston calculated that in 91 minutes the Command Module *Odyssey* would be uninhabitable.

The full extent and cause of the damage were unknown. At first it was theorized that a meteor had struck the spacecraft. This theory was soon discarded. The Smithsonian Astrophysical Observatory at Cambridge, Mass., reported that the chances were a billion to one that a meteor caused damage as large as this. A short circuit was also blamed.

Whatever had happened, the crew had to be returned to Earth immediately.

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Astronauts Lovell, Swigert, and Haise exit helicopter aboard the recovery ship USS Iwo Jima. *The Apollo 13 splashed down at 12:07 p.m., April 17, 1970.*

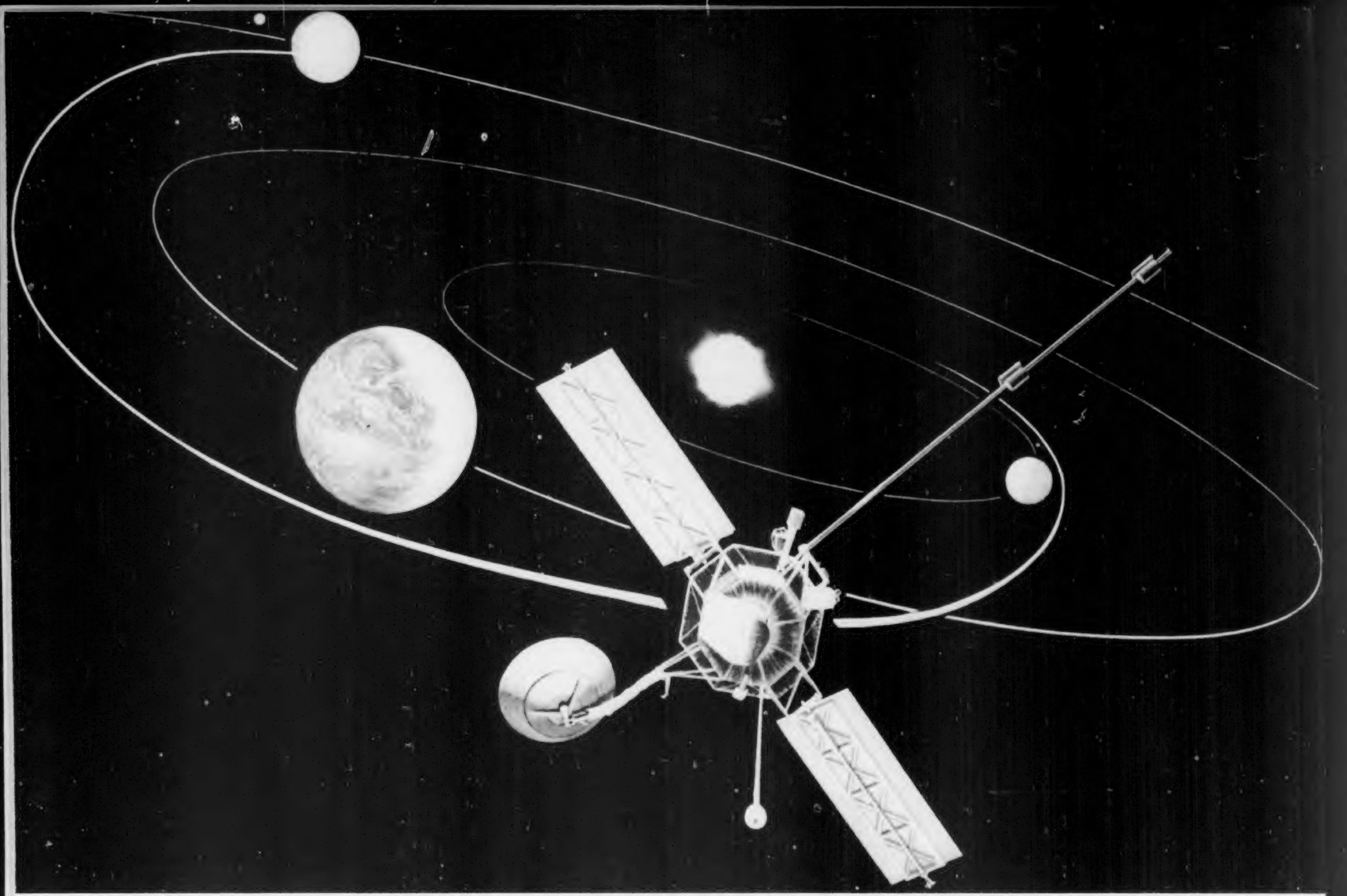

Fig. 1 The path of Mariner 10 from Earth by Venus to Mercury, launched from the John F. Kennedy Space Center in Florida on Nov. 4, 1973.

Ingenuity in Space—Mariner 10

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In this age of high gasoline prices, Americans are of necessity becoming familiar with the concept of fuel-efficient travel. Lighter automobiles with smaller engines are being purchased; routes are more carefully planned than before; and trips that might have been taken separately are now being combined.

Similar problems have always confronted scientists and engineers who plan interplanetary space exploration. Launch vehicles for planetary missions are expensive and use much fuel. Large rockets, which provide the greatest thrust, must carry the most fuel and must be able to lift this additional load during the early, least fuel efficient phases of their flights. These factors combine to severely limit the weight that can be devoted to television cameras, power supplies, radios, and scientific instruments. They also severely limit the routes that can be taken by spacecraft on their way to the other planets.

One of the most impressive accomplishments of the space age is that, even with these constraints, a broad and varied program of planetary exploration has been undertaken. During the 1960s and '70s, missions were launched to all of the known planets except Pluto, the smallest and outermost planet. (Pluto's size is not precisely known, even today. It is normally the farthest planet from the Sun. But its orbit is so eccentric that periodically it moves closer to the Sun than the planet Neptune. That is the case today, and it will remain so until Feb. 22, 1999.)

There is no more impressive example of the efficient use of a launch vehicle than the mission of Mariner 10. It was the first spacecraft to use the gravitational attraction of one body to help it along its way toward another, and it was the first and so far the only spacecraft to visit a single planet more than once.

Launched from the John F. Kennedy Space Center in Florida on Nov. 4, 1973, Mariner 10 passed within 5800 km (3600 mi.) of the clouds of Venus on Feb. 5, 1974. Then, its path altered by the gravity of Venus, the spacecraft continued on to Mercury. Mariner 10 took measurements near that small, barren and relatively unknown planet and sent back television pictures of its surface on Mar. 24, 1974, Sept. 7, 1974, and Mar. 16, 1975.

Planning for Mariner 10 began in earnest during the summer of 1968. The primary goal of the mission was to closely observe Mercury. A secondary but important goal was that the mission be accomplished within a fixed and relatively modest budget of $98 million. The budget constraint made it necessary to use the reliable Atlas/Centaur launch vehicle.

The Atlas/Centaur combination of rockets had become the workhorse of the Mariner Program toward the end of the 1960s. Although the earliest Mariner missions to Mars and Venus, our nearest neighbors, had used less powerful Atlas/Agena combinations, all of the later Mariners, beginning with the Mariner 6 mission to Mars, were larger and used the Atlas/Centaur. Subsequent planetary missions, including Viking and Voyager, have required a still more powerful booster, the Titan III/Centaur, for their accomplishments. But even with the Titan, the possible routes chosen for the Voyager missions have had to use the gravity of Jupiter in order to reach Saturn. Voyager 2 had to use the gravity of Saturn to send it toward Uranus and Neptune.

When Mariner 10's mission was planned, the potential of using "gravity assist trajectories" for reaching otherwise inaccessible planets had only been recognized for a few years. That recognition came largely through the creative and tireless work of graduate student, Michael A. Minovitch, who had been assigned to work on spacecraft trajectories at the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., during the summer of 1961. In 1962, further work by Minovitch led to the discovery that in 1970 and again in 1973 the Earth, Venus, and Mercury would move into positions allowing a trip to Mercury using a relatively small launch vehicle. Such opportunities would not come again for more than a decade.

When an interplanetary spacecraft is launched it is usually first placed in a "parking orbit" around the Earth. In this parking orbit the motion of the spacecraft around the Earth is added to the Earth's own motion around the Sun. To travel to another planet the rocket engines must fire and give the spacecraft enough speed to escape the gravitational pull of the Earth, and at the same time that speed must be in precisely the right direction to change the spacecraft's solar orbit to one that will intercept the other planet as it moves in its own orbit around the Sun. If the acceleration of the spacecraft is in the direction opposite the Earth's motion around the Sun, slowing it down, the spacecraft's orbit will contract to one that approaches near the Sun; if the acceleration is in the forward direction, speeding it up, the spacecraft will assume a larger, more distant orbit. The greater the change that is required in the orbit, the greater must be the velocity change of the spacecraft and greater amounts of fuel will be required. The change of velocity required to directly collapse a spacecraft's orbit from one near the Earth's to one that would intercept Mercury on a path appropriate for taking television pictures and for making other scientific measurements is far greater than can be accomplished with a Mariner class spacecraft launched with an Atlas/Centaur rocket.

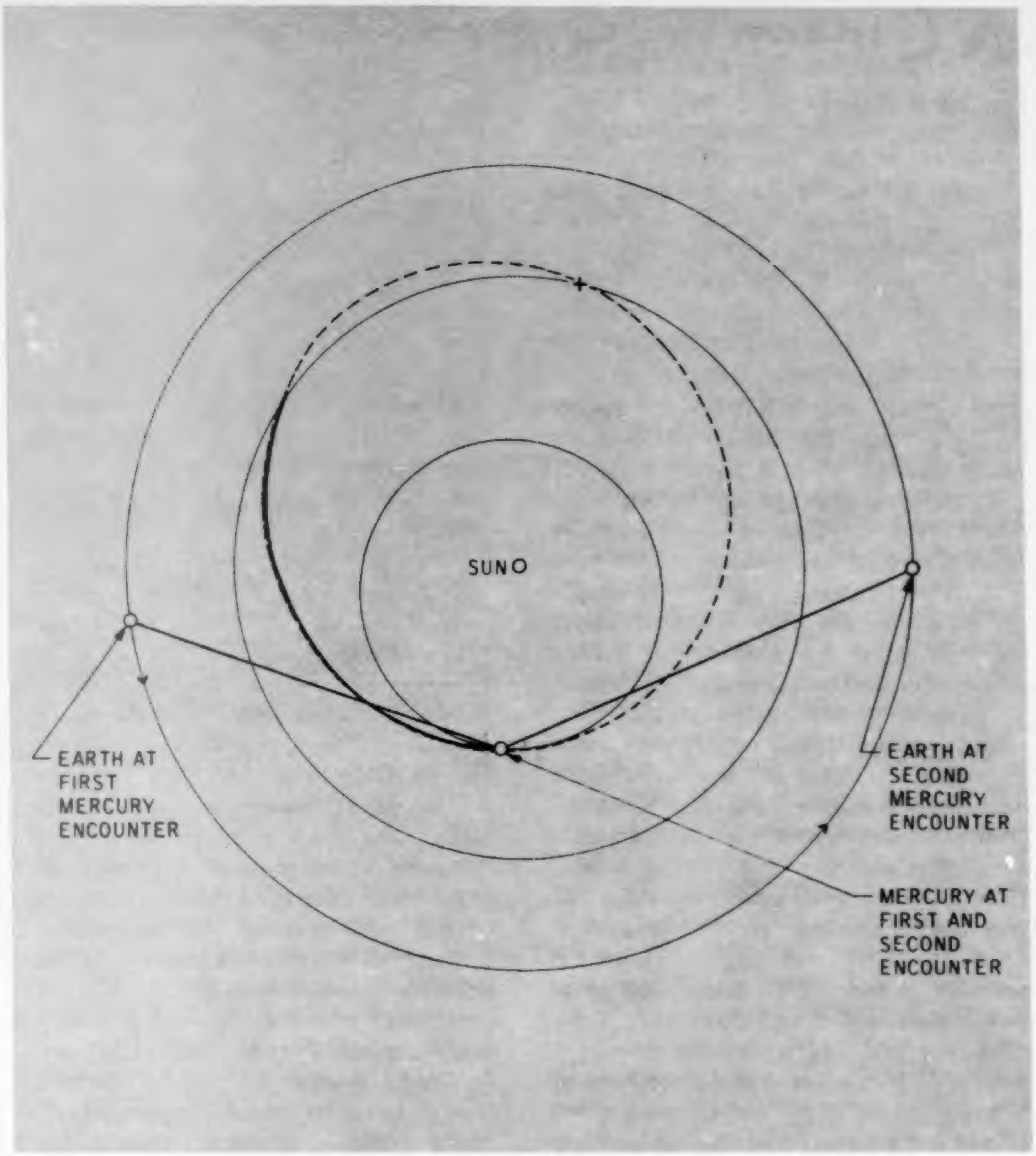

SUN
EARTH AT FIRST MERCURY ENCOUNTER
EARTH AT SECOND MERCURY ENCOUNTER
MERCURY AT FIRST AND SECOND ENCOUNTER

Fig. 2 Post-encounter orbits of Earth, Venus, and Mercury. The eccentric dotted line represents the first complete solar orbit of Mariner 10. In the time it took Mariner 10 to complete its orbit, Mercury had traveled exactly twice around the Sun while the Earth had covered the distance shown.

What the JPL scientists discovered was that if Mariner 10 was carefully guided to pass slightly in front of Venus as the planet traveled around the Sun, Venus' gravitational pull would further slow the spacecraft's motion around the Sun and further collapse its orbit toward the orbit of Mercury. This would happen without the expenditure of any additional fuel (See Fig. 1). JPL scientists and engineers realized that as a bonus, while the Mariner 10 spacecraft flew by Venus, valuable scientific data could be collected.

The taking of pictures and measurements near Venus was not the only or the most dramatic way the yield of scientific data from Mariner 10 was increased. During the Mariner planning conference held at the California Institute of Technology in February 1970, a visiting scientist from Padua, Italy, made a seemingly offhand remark that led JPL scientists to carefully check the post-Mercury trajectory of the spacecraft. According to Dr. Giuseppe Columbo, the Mariner 10 spacecraft would continue indefinitely in a distorted or "eccentric" elliptical orbit around the Sun (Fig. 2), and the period of that orbit would be almost exactly twice the orbital period of Mercury itself. If he were correct, it would mean that additional encounters with Mercury would be possible.

Careful computer analysis by JPL scientists quickly confirmed Columbo's calculation. While Mariner 10 made its first complete post Mercury solar orbit, the innermost planet would travel twice around the Sun and the two bodies would meet again. As it turned out, through careful husbanding of the spacecraft's fuel throughout the flight, two extra encounters with Mercury were achieved. The additional pictures and scientific data from Mercury were obtained for the price of keeping the tracking and communications systems active for an extra year. That was far less than it would have cost to launch another mission from Earth. Mariner 10 indeed set a standard for ingenuity and efficiency in planetary exploration. ■

A Closer Look at Human-Powered Flight

Melvin B. Zisfein
Special Advisor for Technology, NASM

Most people have seen reports, magazine articles, TV news clips, or documentaries on the successful human-powered flights of the Gossamer Condor and Albatross. There is one dimension, however, in which the Gossamer flight team headed by Paul MacCready has not received enough public acclaim and that is in innovative aeronautical engineering.

Some people may regard these flights as interesting stunts performed by super tinkerers and adventurers. In fact, however, the Gossamer aircraft designers are superb aerodynamicists and aeronautical engineers who brilliantly synthesized and analysed a unique and demanding system, the human-powered airplane. The Gossamer Condor, which now hangs proudly in the National Air and Space Museum, was designed to fly, by human power, over a "figure 8" course determined by two pylons set 8/10 km (1/2 mi.) apart. (The Albatross had to fly across the English Channel under human power.)

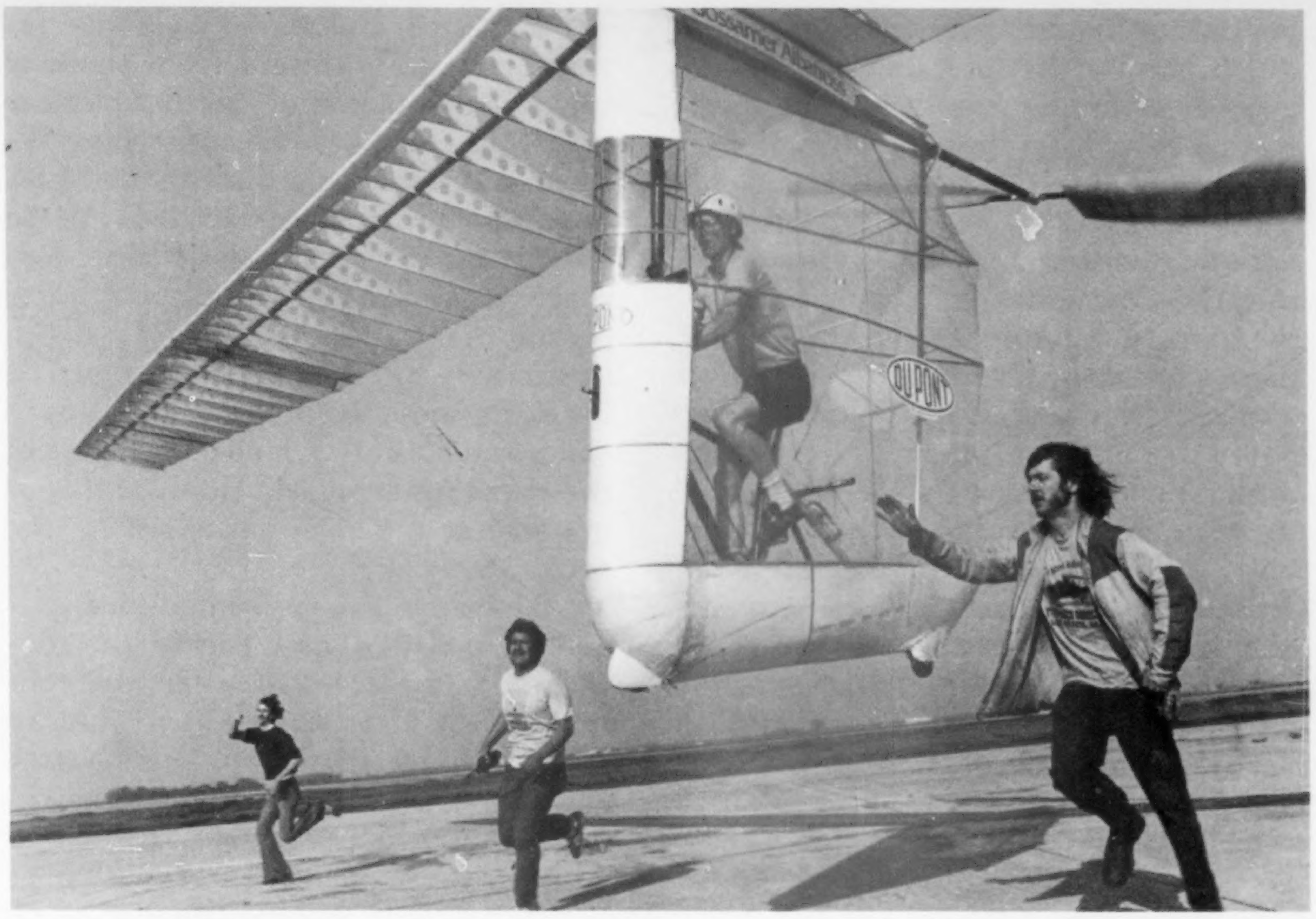
The desire for human-powered flight is reflected in numerous myths and legends, such as the Greek myth in which Icarus and Daedalus escaped from their captivity on the Island of Crete. Although both used feathered-wings held together by wax, only Daedalus escaped successfully. His son, Icarus, flew too near the Sun, which melted the wax in his wings and caused him to plunge into the sea.

MacCready's design team was much better at systems engineering than was Daedalus. Some of the ingenious thought that went into the Gossamer Condor can be understood by studying the accompanying view of the airplane. The unusual configuration, tied together with many exposed struts and wires, is certainly not as aerodynamically "clean" as it might be if it was intended to get maximum speed out of the energy expended by the human operator. However, the systems approach to the problem showed that the lightest possible airplane could be made if it were allowed to be somewhat "dirty" and if it were allowed to fly at a really low speed, 16 kmph (about 10 mph). The pilot would have to pedal longer, but the power input demanded from the pilot just to keep the plane in flight would be much lower than that needed for a much heavier "clean" airplane.

Another example of good systems thinking is the canard surface at the front of the Gossamer Condor, which acts as both a longitudinal elevator-stabilizer and as a rudder. The vehicle is balanced to make the canard surface carry substantial lift in normal flight. Banking the surface transforms much of this lift into a side force at the nose of the airplane, which hauls the nose around as required by the pilot, who changes the bank angle of the canard as needed to keep the airplane flying straight.

This substitute for an aileron and rudder control works well for small turns. For large turns, however, still another lightweight system is used. This is wing warping, which at first glance recalls the system used on the Wright Brothers' Wright Flyer. The wing warping on the Gossamer Condor in flight, however, works just opposite that of the Wright Brothers' (possibly because the Condor flies at 16 kmph (10 mph) and the early Wright airplanes cruised at much higher speeds). On the Wright Flyer, wing warping caused greater lift on the side with the down-warped trailing edge and less lift on the side with the up-warped trailing edge. This caused the airplane to bank and then to turn, using motion-induced forces that greatly resembled the forces on a modern wing-aileron lateral-control system. On the Gossamer Condor, when the pilot activates a special lever to execute a long

The Gossamer Albatross flys over the English Channel, under human power, for France, 1979.



The Gossamer Albatross, flown by Bryan Allen, at Harper Dry Lake, Calif. about 1979.

turn—such as might be required by a "figure 8" course—the wings warp, causing much higher drag near the tip of the side with the down-warped trailing edge than near the tip of the side with the up-warped trailing edge. Therefore, with the same control input, the Wright Flyer would have turned to the left, and the Gossamer Condor would have turned to the right. Despite this difference the Condor's system is simple and light and does the job.

As further evidence of sophisticated thinking, it was recognized that an airfoil for the Gossamer Condor had to be specially designed to yield an efficient wing for flight at about 16 kmph (10 mph). This was done by expert aerodynamicist Dr. Peter Lissaman, a member of the Gossamer airplane team, who used the modern tools of computer-aided design to produce a very low-speed airfoil that has worked very well.

The structural design of the Gossamer Condor may make the configuration aerodynamically "dirty," however, it allows the Lissaman airfoil to be used on a very efficient wing. It is efficient because the structural system allows the wing to have a very long span compared to its chord—so long, in fact, that the ratio of these quantities, called the aspect ratio, is over 12 to 1. This high-aspect ratio wing reduces wing drag due to lift (technically known as the induced drag).

In addition to using external bracing to save weight, the Gossamer airplanes achieve further structural efficiency and lightness by the use of sophisticated materials such as high-performance plastics.

Much has been said about the achievements of the Gossamer Condor and Albatross in winning the 50,000£ and 100,000£ Kremer prizes for performing the feats of flight that these called for. However, it is important to note that the aircraft are not the products of lucky accidents or fast guesses. Rather, they are the products of some highly original and logical thinking combined with some of the best techniques of modern design and analysis. ■

Glossary

Aerodynamically "clean"—Streamlined and free of drag-producing appendages, such as struts, wires, wheels, deployed flaps.
Aerodynamically "dirty"—The opposite of "clean." There are degrees of "dirtiness" such as with struts and wires exposed but wheels and flaps up.
Airfoil—The exterior shape of a cross section of a wing, roughly an elongated teardrop shape rounded at the front and pointed at the rear.
Canard surface—A small horizontal aerodynamic surface placed well ahead of the main wing.
Chord—The straight line length of a wing along a cross section.
Aspect Ratio—Roughly a wing's span divided by its average chord, more precisely: $(\text{wingspan})^2/\text{wing area}$.
Lateral-directional control system—That part of the control system that makes an airplane bank and turn.
Longitudinal control system—That part of the control system that makes an airplane move its nose up or down.
Induced drag—The component of an airplane's drag that is due to its lift, as distinguished from drag due to aerodynamic friction or drag due to stagnant-flow regions behind various kinds of protuberances.
Wing Warping—An aerodynamic control method that makes an airplane turn and bank by pulling on wires, which are so attached that when a control device is moved one wing is warped trailing edge down while the wing on the opposite side is warped trailing edge up.

Continued from p. 13

Mission Control suggested using the undamaged Lunar Module *Aquarius* as a "lifeboat." So, by conserving as much scant electricity and oxygen as they could, the astronauts abandoned *Odyssey* and flew back home in *Aquarius* with *Odyssey* still attached. A blast of *Aquarius'* descent engine luckily operated with perfection and maneuvered the craft toward its proper course.

But because *Aquarius* had no heat shield with which to endure the blazing hot friction of the atmosphere upon reentry, it could not be ridden all the way. Neither was the Service Module built for reentry. Together, the Command and Lunar Modules with the cylindrical Service Module attached began the return to Earth with the three nearly frozen astronauts—the heat had to be turned down to a minimum—surviving as best they could in the *Aquarius*.

It was necessary to jettison the Service Module 4 1/2 hours before reentry. Just as the crippled craft floated away, Apollo 13's crew snapped several photos of it and took movies. For the first time they could see the full extent of the gaping damage. "There's one whole side of that spacecraft missing," exclaimed Lovell in disbelief.

The astronauts' next task was to turn *Odyssey*'s power back on and then crawl through the tunnel that joined it with the Lunar Module. Soon after, the lifesaving *Aquarius* had to be cast off. "Farewell *Aquarius*," radioed Mission Control. Shortly, the thin-walled Lunar Module *Aquarius*, which had been designed (with no heat shield) only to land on the Moon, burned as it reentered the atmosphere. The Command Module bearing its three tired astronauts sped home.

The mode of return had been unorthodox, but it worked. At 1:08 P.M. EST, April 17, 1970, Apollo 13's Command Module *Odyssey* splashed into the Pacific, just 8 km (5 mi.) from the recovery carrier *Iwo Jima*.

There was a full-scale Apollo 13 accident investigation not long after the triumphant return of Lovell, Haise, and Swigert who were treated as full-fledged heroes. It was concluded from a study of the photos and movies of the Service Module as it was cast off, as well as of tapes of the flight and other data, that one of Apollo 13's oxygen tanks had exploded due to a fault in the switching system, which caused electrical overloading.

The technical flaw was easily rectified in later spacecraft, and the accident did not hold up the Apollo program nor future space missions. Man's ingenuity, even in outer space and under great adversity, was amply proven by the Apollo 13 astronauts. This was the real triumph of Apollo 13. ■

Constellations

Von Del Chamberlain
Astronomer
Department of Space Science and Exploration, NASM

The classical Greek and Roman constellations are so familiar that there is a tendency to forget that these are only examples of the many forms that people have imagined among the stars. Indeed, constellation inventing is a universal human activity undertaken by cultures around the world. Constellations form a gridwork for noting and recalling the locations of stars and other objects so that people may communicate about what they see in the sky.

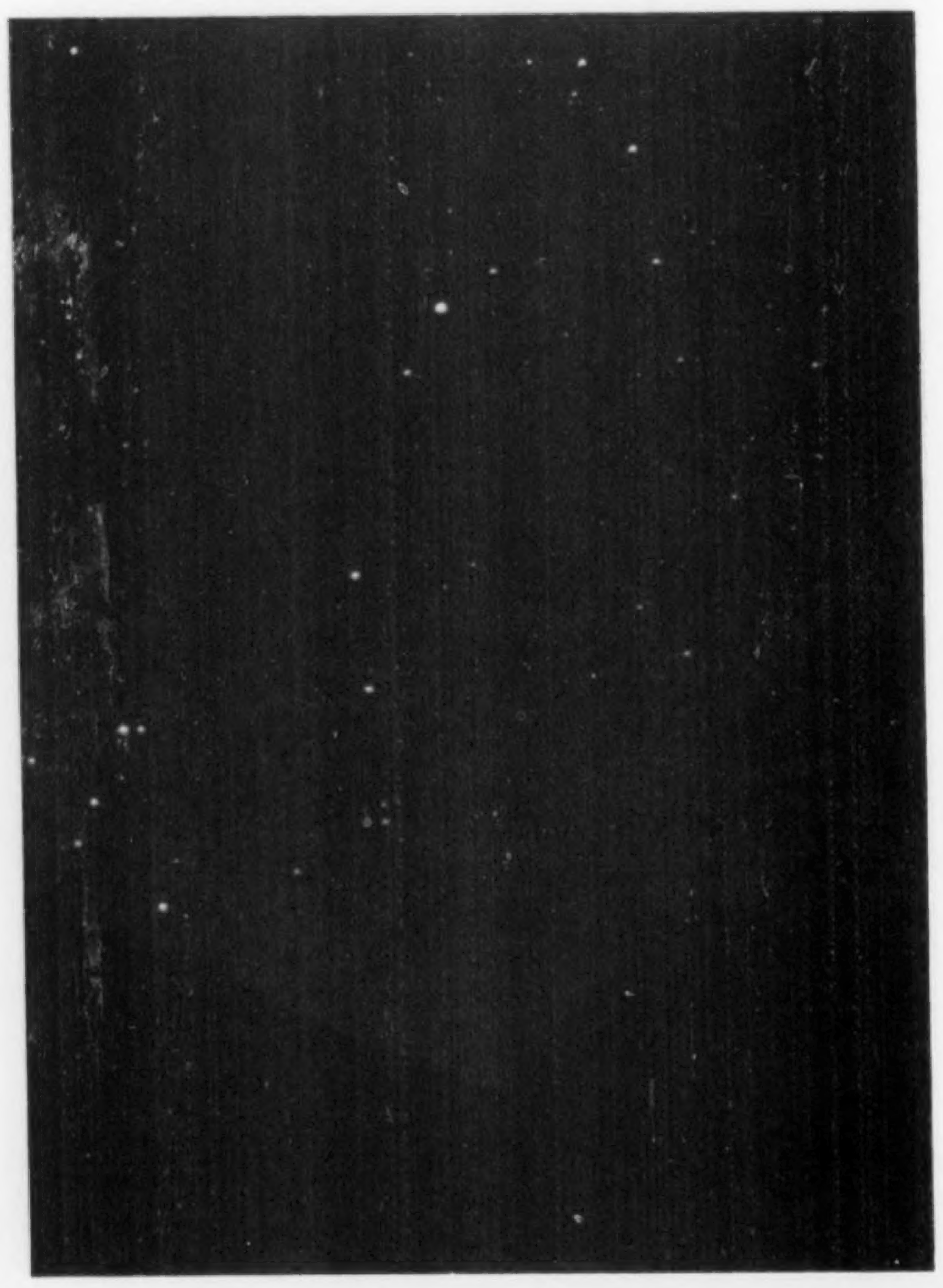
The word constellation may be broken down into its Latin components: *com*, together; *stellar*, stars. People from diverse cultures have seen the same patterns of these "stars together," but they have tended to recognize and group them differently because they associate them with different objects, events, and ideas. Thus, the constellations defined in various cultures reveal something about the development of those cultures— the way that peoples perceive themselves and their histories through their traditions and concepts of relationships of things of the Earth to those of the heavens.

Almost all human groups were aware that there is a point in the sky that does not share in the diurnal, or daily, movement of the stars. The Norse referred to this as the *World Spike*, which holds all of creation together, and called the north star *Polaris*, the *Jeweled Nailhead*. Similarly, the Mongols called the star the *Golden Peg*, which holds the whirling heavens in place. The Chinese, at one time, called the star *Emperor of Heaven* and said it set the pattern that emperors on Earth should follow. This same idea was expressed in America by the Skidi band of Pawnee Indians who referred to the North Star as the *Chief Star* that watched over his celestial tribe to be sure that none lost its way; he also watched over earthlings providing an example of stability, which human chiefs should emulate. We see reflected in this example the extremes in thinking about the stars, both as inanimate objects associated with a rotating celestial sphere and as animate deities of importance to the welfare of people on Earth. Thus we see both similar and different human modes of thinking in very different historical, political, social, and geographic settings.

In the North, the stars wheel about in ever-widening circles as we look farther away from the pole. Thus people in mid-northern latitudes see groups of stars, which are always above the horizon, passing high above the pole-star, then low under the North Star near the horizon. Egyptians once referred to these stars as the *Never Vanishing* or *Imperishable Ones*. The Navajo Indians associated two of these groups of stars with the first male and female people: *Revolving Male*, better known today as *Ursa Major*, which contains the Big Dipper; *Revolving Female*, to us *Cassiopeia*, named after the Queen of Ethiopia in the Greek legend of Perseus and Andromeda. These symbols of the original parents of Navajo humanity constantly revolve around the immovable star considered to be their igniter, or source of fire.

In England, the Big Dipper stars have been called a *Plough*, and in China they once were known as the *Balance of Jade*, which was thought to control the seasons. To the Arabs the seven stars of the Dipper were the *Bier* and *Mourners*. Again we find a parallel in America; the Skidi Pawnee referred to two stretchers in the north, our Big and Little Dippers, which taught the people on Earth how to carry their sick and dead. The four stars of the bowl of each dipper marked the ends of the poles of the stretchers, and the dipper handles were the medicine men and others concerned for the sick or mourning the dead. In many lands, including Greece, the stars of and near the dippers have been associated with bears.

Scorpius *was divided by the Skidi Pawnee and the Navajos into two constellations. The string of stars on the right were the Skidi* Snake *and the Navajo's* First Big One; *the two stars close together at bottom left were the Skidi* Swimming Ducks—*these two stars plus the three beneath them were the Navajo's* Rabbit Tracks.



Some constellations were derived that are quite different from those of today. Australian and South American tribes have imagined constellations formed by dark regions along the Milky Way. The Zuni Indians once spoke of the *Chief of the Night*, a constellation that spanned much of the visible sky; some portion of it was always present at night, no matter what the time or season. The Skidi Pawnee associated the North American bobcat with all of the stars of the sky; thus we could think of this as the largest possible constellation—the entire starry sky.

There are also very small constellations. *The Pleiades*, now part of the constellation *Taurus the Bull*, were once considered by the Greeks to be an independent constellation. This was also the case with most American Indian groups, which in addition, tended to associate these clustered stars with boys rather than girls. Another small constellation is *Delphinus*, the Dolphin, which the Skidi Pawnee called the *Bow* and symbolized the bow given to the first man so that he might kill animals for food. Many cultures divided *Scorpius*, the Scorpion, into two constellations: the Navajos called the body of the Scorpion the *First Big One* and the tail, *Rabbit Tracks;* the Skidi Pawnee referred to the body as the *Snake*, and they called the two stars marking the stinger the *Swimming Ducks*. The first appearance of the Duck stars in the morning sky, combined with Springtime thunder, marked the time of renewal of life and set the Skidi ceremonial calendar.

Finally, our modern set of 88 constellations, covering the entire sky, includes some that were recently invented. These are often easily recognized with names like *Antlia* (the Air Pump), Microscopium (the Microscope), and *Telescopium*, (the Telescope).

We have considered only a few of the thousands of examples of constellations as they are conceived around the world. Constellations are part of cultural cosmology and studying them, as they were defined and named worldwide, can tell us much about how cultures developed and how ideas and knowledge diffused from place to place and from times past to the present.

Suggested Readings

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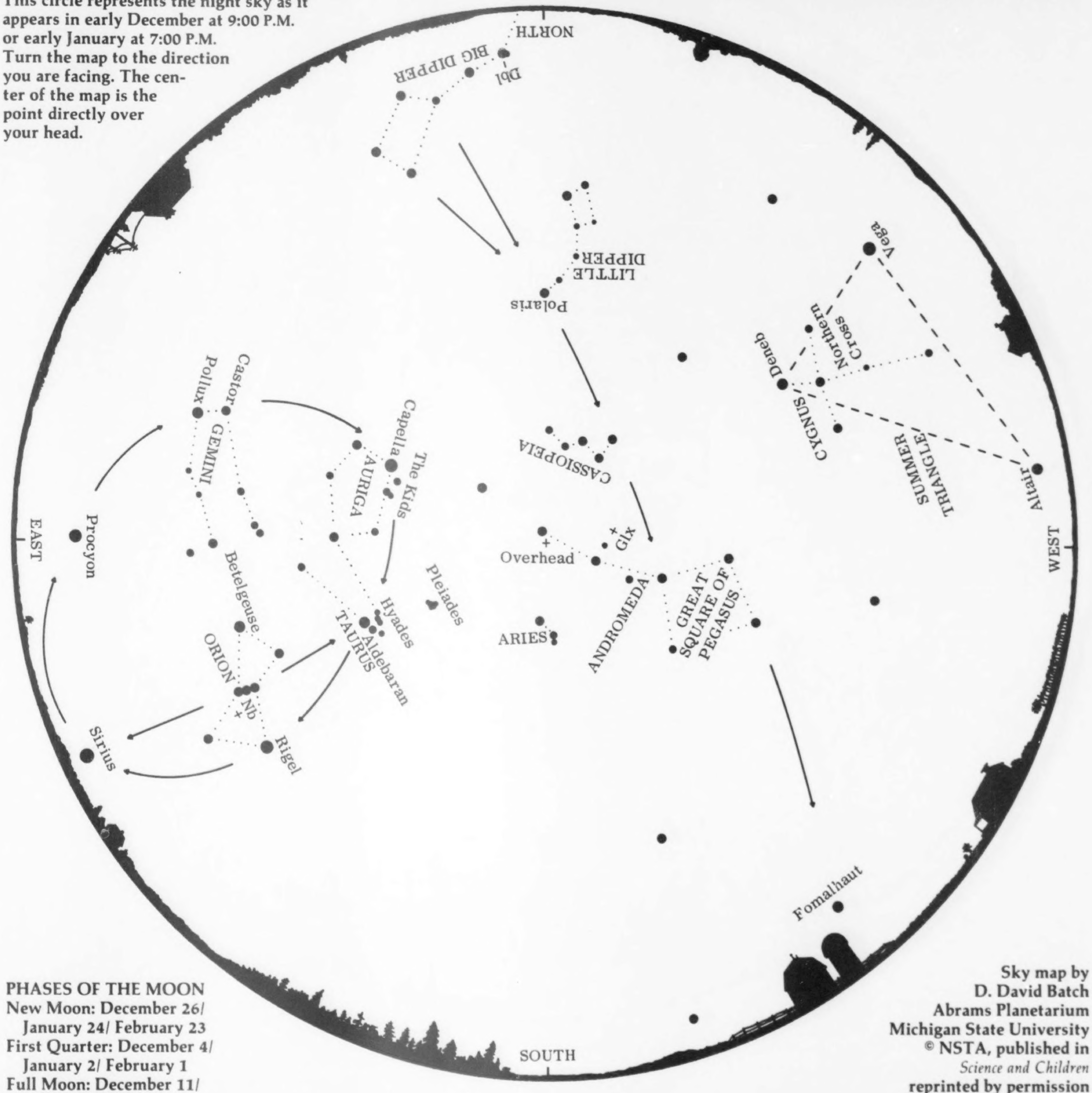
Winter '81 Sky Map

By T.H. Callen II
Production Specialist
Albert Einstein Spacearium, NASM

This circle represents the night sky as it appears in early December at 9:00 P.M. or early January at 7:00 P.M. Turn the map to the direction you are facing. The center of the map is the point directly over your head.


NORTH
BIG DIPPER
Dbl
LITTLE DIPPER
Polaris
Vega
Northern Cross
Deneb
CYGNUS
SUMMER TRIANGLE
Altair
WEST
CASSIOPEIA
Glx
Overhead
ANDROMEDA
GREAT SQUARE OF PEGASUS
ARIES
Pleiades
Hyades
Aldebaran
TAURUS
The Kids
Capella
AURIGA
Castor
Pollux
GEMINI
Procyon
EAST
Betelgeuse
ORION
Nb
Rigel
Sirius
Fomalhaut
SOUTH

PHASES OF THE MOON
New Moon: December 26/ January 24/ February 23
First Quarter: December 4/ January 2/ February 1
Full Moon: December 11/ January 9/ February 8
Last Quarter: December 18/ January 16/ February 15

Sky map by
D. David Batch
Abrams Planetarium
Michigan State University
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Pollux and Castor, the two brightest stars in the constellation Gemini, are classically referred to as twins, but they are only fraternal twins at best. While Pollux is a normal, golden-colored giant about 35 light-years (LY) (3.3 x 10^{14}km) away, Castor, at 45 LY, is by far the more unusual of this famous pair.

Located about 4° from Pollux, Castor appears to the unaided eye as a single star. Through amateur telescopes, however, two stars, Castor A and B, are visible. Both stars are white; Castor A is about twice the size of the Sun and Castor B about 1.5 times; Castor A gives off 12 times as much light as the Sun and Castor B, about 6 times. This beautiful, gravitationally bound pair is physically separated by a distance of 90 astronomical units (AU) (1.4 x 10^{10}km), a little more than twice the diameter of the Solar System, and they orbit each other once every four centuries. About 1000 AU (1.6 x 10^{11}km) away lies yet a third companion, Castor C. This star, a red dwarf about three-quarters the size of the Sun, is so far away from the other two that it would take 10,000 years or more to orbit Castor A and B.

Our stellar saga does not end here, as each of these three visible components has an unseen, or spectrographic, companion, bringing to six the total number of stars making up what we call Castor! Spectrographic binary companions are not really invisible, but are so close to the visible star that they can only be detected by using a spectrograph. As these stars orbit each other, their stellar footprints, or spectra, can be used to find the relative mass of the pair. Even though Pollux and Castor are dramatically different stars, it is hard not to think of them as the twins who sailed with Jason and the Argonauts for the Golden Fleece whenever we see them on a crisp winter's night.

New Book from NASM

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48 pp.; 24 b & w photos; 37 color photos; 6 x 9⅛ inches; paper, $2.75; (shipping/handling $1.50).

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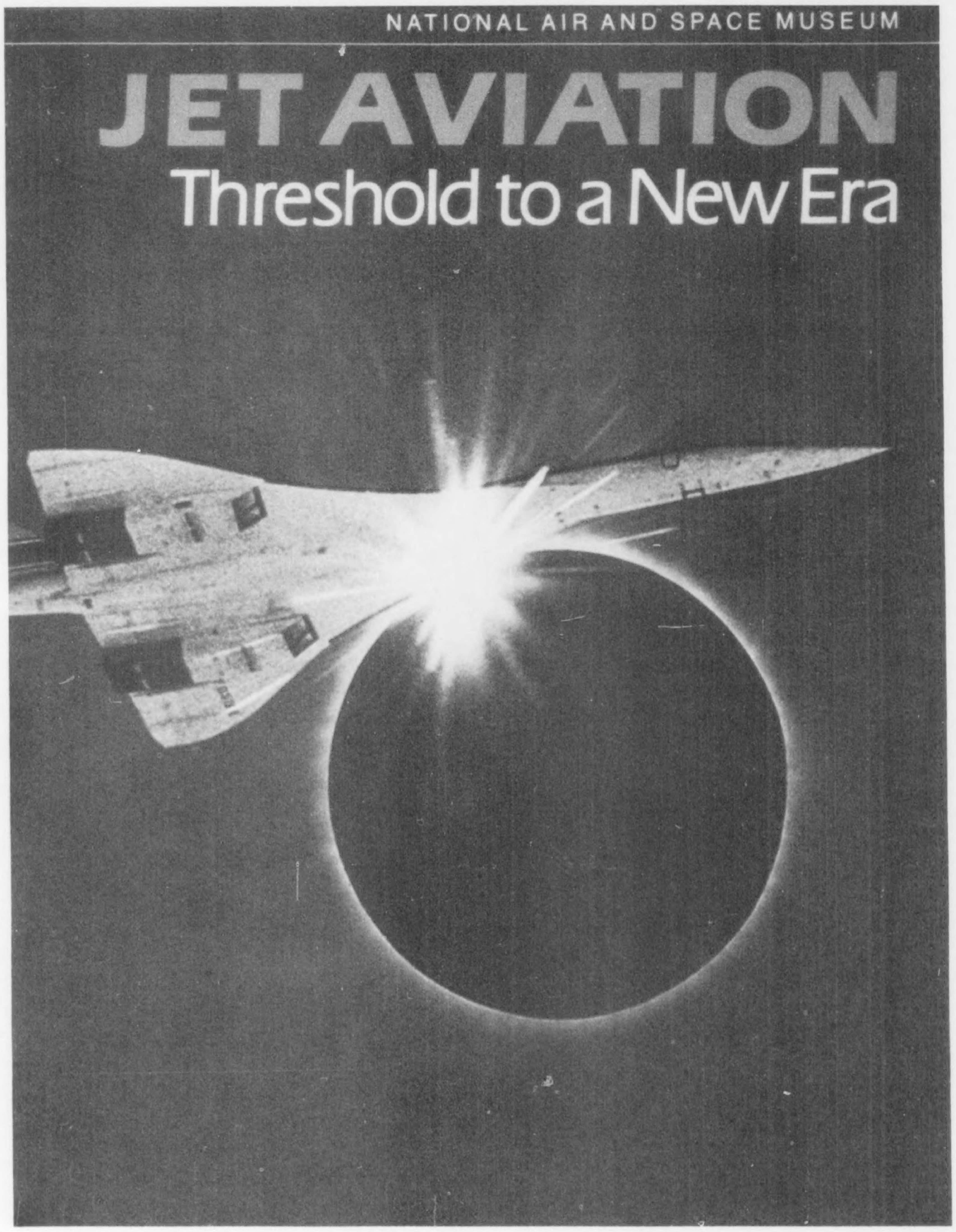

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JET AVIATION

Threshold to a New Era

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The fifteenth annual National Congress on Aerospace Education will take place April 1-3, 1982, in Atlanta, Georgia, at the Sheraton-Atlanta Hotel. Sponsors for this year's congress are Civil Air Patrol, Federal Aviation Administration, National Aeronautics and Space Administration, and the National Air and Space Museum. For more information, please write National Congress on Aerospace Education, HQ CAP/EDF, Maxwell AFB AL 36112.

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